REPORTS

ON

TOTAL SOLAR ECLIPSES

[illegible]

U. S. NAVAL OBSERVATORY,

REAR-ADMIRAL B. F. SANDS U. S. N.

SUPERINTENDENT.

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WASHINGTON OBSERVATIONS FOR 1869.—APPENDIX I.

REPORTS ON OBSERVATIONS

OF THE

TOTAL SOLAR ECLIPSE

OF

DECEMBER 22, 1870.

CONDUCTED UNDER THE DIRECTION OF

REAR-ADMIRAL B. F. SANDS, U. S. N.,

SUPERINTENDENT OF THE U. S. NAVAL OBSERVATORY, WASHINGTON, D. C.

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REPORT

OF

REAR-ADMIRAL B. F. SANDS, U. S. N.

REPORT OF REAR-ADMIRAL B. F. SANDS, U. S. N

UNITED STATES NAVAL OBSERVATORY,
Washington, July 15, 1871.

SIR: The officers of the Observatory, detailed by the Navy Department for observations of the late eclipse of the sun of the 22d December, 1870, having returned from that duty, I have the honor to forward herewith their reports.

After the successful results of the observations of the eclipse of August 7, 1869, by the officers of this Observatory, it was desirable that their experience should be taken advantage of for the further elucidation of the subjects involved in such phenomena; and the eclipse to occur in Europe on the 22d December, 1870, was discussed with a view to their taking part in the observations on that occasion, as one of the legitimate and appropriate duties of the Naval Observatory.

The Navy Department was addressed by me upon the subject, which resulted in the detail for that duty of Professors Simon Newcomb, Asaph Hall, William Harkness, and J. R. Eastman, of the United States Navy, attached to this Observatory, all of whom had contributed largely to science by their reports of the August eclipse.

It was, at first, intended to have the parties accompanied by a skilled photographer and other observers not attached to the Observatory; but having no special appropriation for the purpose, and our contingent fund being too limited to meet the expense that would be incurred, we had to restrict ourselves to the officers of this institution already experienced in such observations.

The last three of the officers mentioned above were directed to proceed to Sicily, to occupy some convenient points near Syracuse, each in his distinct and separate duties, with independent instructions for each—Professor Hall for observations upon the corona, Professor Harkness for spectral analysis, and Professor Eastman with polarizing apparatus and meteorological instruments; with directions to avail themselves of any assistance they might be able to obtain in the localities selected.

Professor Newcomb, having been previously detailed for other special duties in Europe, was instructed also to occupy some point near Gibraltar for general observation of the eclipse and physical constitution of the corona, and other observations to determine the path of the center of the shadow over the earth, with the object of obtaining data for the correction of the lunar tables, by comparing these results with those previously calculated from them.

While in England, *en route* for his station, Professor Newcomb, through the courtesy of the Astronomer Royal, Mr. Airy, and of Sir James Anderson, the president of the Anglo-Mediterranean Telegraph Company, made very elaborate arrangements to correct the stations of our observers by cable for difference of time with the Greenwich Observatory. This was accomplished between Sicily and Malta and Gibraltar, and failed with Greenwich only in consequence of a break in the cable between that place and Lisbon, which could not be repaired during Professor Newcomb's sojourn at Gibraltar.

By special invitation, Professor Newcomb accompanied the English party to Gibraltar on board H. B. M. Steamer Urgent, arriving in time to make the necessary preparations for telegraphic difference of time with Greenwich, Gibraltar, and Malta.

Professors Hall, Harkness, and Eastman arrived at Syracuse with their instruments in ample time to make every preparation, and selected their several positions near that city. Mr. Hall and Mr. Harkness, in the mean time, at Malta and Syracuse respectively, in connection with Mr. Newcomb at Gibraltar, determined by telegraphic cable the difference of time between those places. Cloudy weather with high winds made the Sicily observations less successful than we had hoped, but they tend to corroborate those of our parties in America on the 7th August, 1869, and form interesting addenda to those of that year on this continent.

In accordance with the course I had adopted in the administration of the duties of Superintendent, to give to each of the officers the full credit of his work, and that they may share the responsibility attendant upon their observations, I have the pleasure to forward to the Department their very interesting reports

entire, and over their several signatures. Constituting as they do very valuable contributions to the science of astronomy, evincing great ability and personal interest in the subject, most creditable to the observers and highly honorable to the institution of which they are prominent members, it would be unjust to the officers, and detract from the merits of the reports, to abridge or condense them.

The letter of Captain Tupman, R. M. A., who volunteered to assist Professor Harkness, containing his notes and other remarks, is also given entire at the end of Professor Harkness's report. The reports have been delayed to this date by the severe illness of Mr. Harkness in Europe, and the detention of Mr. Newcomb by other duties on which he was engaged, and which were protracted by the war in Europe.

It is most gratifying to record here the very great courtesy and kindness extended to our officers by the savants of Great Britain and the continent—setting aside national jealousies and forming one great brotherhood of science. To each of those learned and distinguished gentlemen I have had the pleasure to address a letter expressing my appreciation of the attentions thus shown. They are mentioned by name in the several reports of our officers.

Through the courtesy of the Secretary of State, Hon. Hamilton Fish, we secured the ready acquiescence of the foreign legations of England and Italy for the passage of the instruments used through the several custom-houses.

I have the honor to be, very respectfully, your obedient servant,

B. F. SANDS,
Rear-Admiral, Superintendent.

Hon. G. M. ROBESON,
Secretary of the Navy, Washington City.

REPORT

OF

PROFESSOR SIMON NEWCOMB, U. S. N.

REPORT OF PROFESSOR NEWCOMB, U. S. N.

BERLIN, *March* 21, 1871.

COMMODORE: I have the honor to present the following report of my observations of the total solar eclipse of December 22, last, made in compliance with the orders of the Honorable Secretary of the Navy. As my proceedings were necessarily determined by the character of the observations to be made, I ask leave to begin by calling to your mind the plan of work marked out for me.

The great number of spectroscopic parties, who were expected to take part in the observations, made it desirable to choose some less occupied, though, it might be, less brilliant field. It was therefore determined that I should simply scrutinize the physical constitution of the corona, as it appeared through the telescope employed in the observations of partial phase. The question kept more particularly in mind was one respecting which the testimony of previous observers is very discordant, namely, whether there is any appearance of structure in the formation of the corona, or whether its different parts seem to run into each other by insensible gradations; in other words, whether the corona is composed of bright points, filaments, and rays, or whether its light is soft and milky. In the former case, it would be proved that the corona could not result solely from an elastic atmosphere surrounding the sun, while in the latter this question might still be an open one.

Another object was to determine, with as much accuracy as possible, the path of the center of the shadow over the surface of the earth, and the time of its passing a given point, in order to compare these results with those previously calculated from the lunar tables, and thus obtain data for the correction of the latter. The relative positions of the sun and moon can indeed be determined by observations of an eclipse at points far removed from the central line. But the observations for this purpose, as usually made, are subject to various unavoidable sources of error, which it is not necessary to enumerate. On the other hand, when the observer is on or near the line of central eclipse, observations for this purpose can be made with great precision, and my arrangements were planned with the view of putting in practice a very accurate method of observation, which, if not new, has fallen into almost complete desuetude. This method is founded on the geometrical theorem that the line joining the cusps of the partially eclipsed sun is at right angles to the line joining the centers of the sun and moon, so that the angle of position of the latter line can be immediately inferred from that of the former. The advantages of the method arise from the great extent to which the errors of the ordinary class of observations may thus be diminished. During the last century, observations of solar eclipses have been generally confined to determinations of the times of contact of the limb of the moon with that of the sun or with spots on its surface. The latter furnish no data for fixing the position of the moon, because the positions of the spots are never accurately known. The former generally consist of observations of external contact, or moments of the beginning and end of the eclipse. But if we consider the question with mathematical accuracy, we must admit that an actual external contact of the limb of the moon with that of the sun cannot be observed, because the former cannot be seen until it has impinged on the latter to an appreciable extent. If the magnitude of this extent were constant, it could be easily determined and allowed for. But, unfortunately, it is a very variable and uncertain element, depending on the observer, the telescope, and the nature of the moon's surface, smooth or rough, at the point of contact. Observations of last contact are indeed less in error from this cause than those of first contact, but they still exhibit very large discrepancies.

Observations of internal contact in annular and total eclipses are free from the source of error here considered. But they are still subject to the uncertainties arising from the inequalities of the moon's surface; and when made, as is usually the case, at points near the line of central eclipse, they afford no data whatever for determining the error of the moon's latitude, or the path of the line along the earth's surface. To be useful for this purpose, observations of contact must be made at points near the limits of annular or total phase. We have occasional observations so made at public or private observatories, which chanced to lie in the proper position relatively to the moon's shadow; but I know of only two total eclipses in which systematic arrangements were made to determine by observation the path of the moon's shadow along the sur-

face of the earth. These were the eclipses of 1715, in which the moon's shadow passed over England, and that of 1869, in which it passed over the United States. The method adopted in the latter was substantially identical with that employed by Halley in the former, and consisted in securing observations of the simple duration of total phase by intelligent inhabitants at various points near the limits of totality. Though this method is the best yet used, it is not always satisfactory or practicable. The limits of the shadow are themselves rendered uncertain by the irregularities of the moon's surface, besides which we require an accurate knowledge of the positions of all the observers before the observations can be utilized. Of course the observations can be made only in those rare cases when the shadow passes over a well-populated country. But knowing from observation the angle of position of the line joining the center of the sun and moon at any moment, we can thence infer the direction of the center of the shadow at that moment. By making a number of determinations of this angle, as seen from any point in or near the shadow while the latter is passing, the path of its center can thence be inferred with great accuracy. It is true that the error of any isolated measure arising from inequalities of the moon's surface will be of the same magnitude with that of an observed contact. But all the measures being made on different parts of the moon's contour, as the solar crescent seems to move around the moon, the errors arising from irregularity of contour will be almost entirely eliminated from the mean result. My trial of this method convinces me that the observations of the sharp cusps can be made with even greater precision than I had anticipated.

The direct determination of the line joining the cusps is, however, scarcely practicable, owing to the breadth of the solar disk, which prevents the observer from setting a wire simultaneously on the two cusps, unless the telescope be moved by clockwork and a low power be used. We have therefore to substitute differences of right ascension of the cusps, which may be obtained by observing transits of the two cusps over the wires of an equatorially mounted telescope. This was the mode of observation actually adopted, the telescope employed being the comet-seeker of the Observatory. The instrumental arrangements will be more fully described in connection with my observations, which I shall preface with an account of the preliminary operations made to secure the success of the proposed plan.

I sailed from New York, in compliance with my orders, and reached London on November 1st. My instructions left me at liberty to select that point along the line of totality the longitude of which could best be determined by the electric telegraph, an accurate longitude being required before my observations could be used. Immediately on my arrival in London I therefore sought an interview with the Astronomer Royal, to confer with him respecting the choice of a station, and to request his co-operation in the work of determining the longitude of such station as might be selected. It was soon found that Gibraltar was in this respect the most favorable point along the path of totality, as it was in direct telegraphic communication with England through the Falmouth, Gibraltar and Malta cable. The Astronomer Royal entered into my plans in the most obliging manner, agreeing to send time-signals from the Royal Observatory to my station whenever the two points could be put in telegraphic communication, and using his influence to secure such communication. To attain this end, he introduced and recommended me to the engineer-in-chief of the government telegraphs, R. S. Culley, Esq. Mr. Culley most cordially tendered us the use of any of the telegraph lines that might be under his control. It only remained to ask for the use of the cable, and this I did in conjunction with Mr. G. W. Dean of the Coast Survey, who had been instructed by Professor Peirce to co-operate with our parties whenever the interests of science could be so advanced, and whose experience in telegraphing longitude-signals through the ocean-cables made his counsel of great value. We arranged for an interview with Sir James Anderson, managing director of the cable, on the following Monday. At this interview, the distinguished director expressed the great pleasure it would give him to do everything in his power to insure the success of our observations, and offered to place the cable at our disposal at such times as we might require it for the transmission of signals. As the cable was least loaded with business on Sunday afternoons and Monday mornings, it was agreed to select these times for transmission if weather permitted of our correcting our chronometers by astronomical observations.

It only remained to frame a plan of operations for the transmission of signals, which I did, after consultation with the Astronomer Royal and Mr. Dean. The unfortunate failure of the scheme through a cause beyond human foresight and control deprives both my plan and my further proceedings under it of nearly all their interest. However, I inclose a copy of the plan as evidence of the care with which the operations were arranged. To guard as far as possible against all possibility of failure, Sir James Anderson advised me to visit the telegraph office at Porthcurno, the terminus of the cable, and assure myself that all the arrangements for transmitting signals were properly made and understood by the operators. I started on this journey

December 2d, and on the very same day I was advised that a fault had occurred in the cable between Lisbon and Gibraltar. As it was expected that the fault would be speedily found and repaired, I made no change in my plan of operations, and completed the proposed journey. The hope in question was, however, not realized, so that no time-signals could be transmitted at all. The failure of the cable at this moment was most unfortunate for us, because, had I not fully expected to obtain a telegraphic longitude, I should have tried to organize a chronometric expedition for the same purpose, and, I believe, would have succeeded. But it was now too late to do so; indeed, I did not return to London at all after my visit to Penzance.

During my stay in London a joint committee of the Royal and Royal Astronomical Societies was engaged in organizing an expedition for the observation of the eclipse. Having secured from their government the grant of a ship, they invited me to accompany them to Gibraltar. I accepted this flattering invitation, and therefore proceeded from Porthcurno direct to Portsmouth, the port of departure. We sailed on Tuesday, December 6th, in H. B. M. Ship Urgent, on which I was, during a week, the guest of the English expedition. We reached Gibraltar, after a rough passage, on the morning of December 14th.

I first called on the American consul, H. J. Sprague, Esq., and made known to him the object of my visit. He informed me that my instruments, which had been forwarded by the consul at Liverpool, had arrived in safety. I then called on Mr. De Sauty, superintendent of the Gibraltar office of the telegraph company, and learned that Professor Hall was awaiting me at Malta in order to exchange time-signals. I arranged for the exchange on the two following days.

The business next in order was to make the object of my visit known to the authorities. Accordingly, on Friday, Mr. Sprague presented me to His Excellency Sir W. F. Williams, of Kars, the governor of the fortress, who most obligingly tendered me every facility in his power for making my observations from any station I might select within his jurisdiction. The selection of a station was, however, no easy matter. None of the authorities I consulted advised a point within the town, for the reason that during an east wind the latter is always covered with fog, though the sky may be clear both to the north and the south. A station far enough north to avoid this evil would be on Spanish soil and would be subject to several inconveniences, one of which would be the impossibility of any communication with the telegraph office or the town at night. A station to the south was objectionable because farther removed from the line of central eclipse, which passed some twenty miles north of Gibraltar. As this seemed to be the least of the evils, I selected a point known as Buena Vista, about half-way between the town and Europa Point. Its position relatively to some other points in the fortress was as follows, the distances being given in round hundreds of feet, as measured on a large map:*

8,800 feet south and 1,400 feet east of telegraph office.
6,900 feet south and 800 feet east of American consul's house, Edward's Road.
5,600 feet south and 1,100 feet west of Signal Tower.
2,700 feet south and 2,000 feet east of base of new mole.

According to the Admiralty Chart of 1864, the position of the flag-staff near the latter point is latitude 36° 7′ 10″; longitude $0^h\ 21^m\ 25^s.1$ W.† This would make the position of my station

Latitude, 36° 6′ 43″ N.
Longitude, $0^h\ 21^m\ 23^s.4$ W.

The latitude derived from my sextant observations is

$$36° \ 6' \ 51'',$$

with a probable error of four or five seconds. The difference of eight seconds is quite unimportant in the case of the eclipse observations.

Having signified my choice of a station to the governor, his excellency immediately directed that I should be supplied with anything in the shape of military stores I might require. I thus received everything necessary for the protection of my instruments, including tents and a guard.

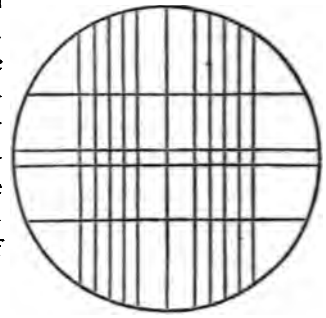
The instruments were conveyed to the station on Saturday, and the work of getting them into position was commenced on Monday. They consisted of the observatory comet-seeker, which was fitted up for the observation of the eclipse itself; a small portable transit, by Würdemann, of about two inches aperture,

*There is probably an error of about 5° in azimuth in these measures, the direction of the supposed meridian being really N. 5° W. and S. 5° E.

†The chart of July 27, 1869, gives a longitude 2^s less.

made for the Northwestern boundary survey, and loaned to the expedition by the Chief of Engineers of the Army. For the determination of latitude and time I had also a Gambey sextant with artificial horizon.

The comet-seeker is an equatorially mounted telescope, of thirty-two inches focus and four inches aperture. When turned on the sun the aperture has to be reduced to two inches or less, owing to the intensity of the heat concentrated at the eye-end when the full aperture is used. Its small size is partly compensated for by its fine definition. A power of forty was selected for the observation of the eclipse. The eye-piece was furnished with a diaphragm of eleven vertical and four horizontal-wires, arranged as in the accompanying diagram, by Mr. Gardner, instrument-maker at the United States Naval Observatory. The intervals between the closer vertical wires are approximately each $2\frac{1}{2}'$ of arc, or 10^s of time, while the wider intervals on each side of the center wire are $5'$ of arc. The extreme distance between the outside wires is therefore $30'$, or a little less than the Sun's diameter. The eye-piece could be turned into any required position, so that the term vertical, as applied to the eleven wires, is only a relative one. A notch was cut into the eye-piece to indicate a fixed position of the latter in which the central wire coincided accurately with the meridian of the instrument. There was no other means of fixing or determining the angle of position of the wires. The direction of the polar axis of the instrument admitted of no adjustmenr for latitude; but Gibraltar being less than three degrees south of Washington, it was easy to elevate one side of the base of the instrument enough to secure the adjustment in question. Both axes of the instrument have divided circles, and each circle is read by two opposite verniers, which give single minutes in declination and spaces of four time-seconds in R. A.



The transit-instrument was mounted on a cast-iron stand. For the adjustment of level and azimuth one Y was movable horizontally and the other vertically. Both movements were effected by micrometer-screws with divided heads, a feature very convenient for the determination of the instrumental constants. The reticule consisted of seven vertical and two horizontal wires. The instrument was supplied with two spirit-levels for leveling the axis.

As it was not easy to get solid stone piers for the instrument, I adopted the plan of using the outside packing-cases, well packed with sand, for the supports. For the transit the box was packed slightly more than full, so that when the top was nailed down its upper surface was rendered slightly convex by the pressure of the sand below. The stability of the instrument, though ample to determine the local time for observation of the eclipse, would not have sufficed for any accurate astronomical determination.*

The comet-seeker was mounted under a tent in such a way that by slightly changing the position of the latter through its supporting cords the instrument could be either entirely covered in, or could be left far enough out to command the southern half of the heavens. On the day preceding the eclipse I got it adjusted to the diurnal motion of the earth as nearly as seemed practicable with the rough means at my disposal. The reticule was adjusted on a distant object, so that the middle right ascension wire was as nearly as possible in the plane of motion of the instrument in declination; after the adjustment was made, however, the top of the wire seemed to incline to the east by the smallest appreciable amount. In the day and evening observations were made to determine such of the instrumental errors as it was necessary to know. During this entire day the sky was cloudless, and everything gave promise of a fine day for the eclipse.

The morning of the 22d dawned with equal promise. At 8 o'clock only a few light and fleecy clouds were to be seen in the sky. A little before nine I observed the transit of β Ursæ Minoris with the transit-instrument. But before I could get another observation clouds began to cover the sky, and an hour before the time of commencement of the eclipse the southern heavens were covered with clouds, mist, and fog, which came in from the Atlantic. There was still much blue sky to be seen in the north, so that I thought I should have done better to observe from the town. In another half hour this had also disappeared, the instruments had to be covered to protect them from the rain, and the prospect seemed hopeless. But a short time before the commencement, fugitive glimpses of the sun began to be obtained through the clouds. I took my seat at the telescope and got a very good view of first contact at $22^h\ 52^m\ 35^s$, chronometer time.

* To each error of one second in the determination of time would correspond an error of $0''.4$ in the longitude of the moon deduced from the observation. The instrument was steady enough to give the local time certainly within a fourth of a second, so that the deduced longitude of the moon could not be $0''.1$ in error from this cause.

This was the moment at which I began to see the limb of the sun indented by the rough edge of the moon. The actual first contact must have occurred an appreciable time, probably two or three seconds, sooner. I then turned the eye-piece so that the R. A. wires of the eye-piece were at right angles to the chord of the eclipsed portion of the sun, and noted the moments at which the length of the chord was measured by certain wire intervals. These observations were rendered difficult and uncertain by the flying clouds, which would at one moment shut the sun off entirely and at another suddenly let him shine with full brilliancy. However, I give the observations *in extenso* in the accompanying papers.

Again the sun was completely hidden, and again the instruments had to be covered from the drizzling rain. Half an hour before the total phase, when I wanted to measure the cusps, the clouds again partially cleared away, so that I was able to obtain several sets of transits of the cusps over the R. A. wires of the comet-seeker between and through the rapidly driving clouds. For this purpose, the eye-piece was restored to its vertical position by the notch made for that purpose.

During the five minutes preceding the total phase the prospect of seeing the latter looked as dark as ever. Once more, however, the clouds broke up at the critical moment. A minute or two before the disappearance of sunlight, what little was left of the sun appeared through the clouds, and I again turned the eye-piece so as to measure with the R. A. wires the length of the vanishing crescent, having first removed the cap from the telescope so as to see with the full aperture of four inches. But in the hurry and confusion of the moment I did not get a measure. I noticed, however, that when the crescent was reduced to about 90°, the ends began to break off and disappear. This process went on with increasing rapidity until $0^h\ 18^m\ 35^s$ chronometer, when all that remained of the crescent was broken up throughout its entire length. The fragments thus formed disappeared one by one, and the last one vanished at $0^h\ 18^m\ 37^s$. I judge that the true time of second contact should be considered about the mean of these two moments, or $0^h\ 18^m\ 36^s$.

As soon as I had recorded the time of disappearance I put my eye again to the telescope. Instead of the gorgeous spectacle I witnessed in 1869, I saw only the most insignificant corona, although the full aperture of the telescope was used. Supposing that this was of course due to the clouds, I kept my eye at the telescope in hopes of their disappearance, still, however, scrutinizing the phenomena most carefully. I could not see the slightest trace of bright or dark points, rays, or filaments, the light everywhere seeming as soft and diffused as the zodiacal light. There were, indeed, as in former eclipses, great differences between the extent and brilliancy of the corona at different points, but all the parts seemed to shade into each other by insensible gradations. The protuberances on the eastern limb of the sun were numerous and brilliant, presenting the many fantastic forms which photography has rendered so familiar. But they presented no appearance of structure, as did the great protuberance in the eclipse of 1869. The light and color of all were sensibly uniform throughout their entire extent, and their outline was sharply defined. So far as I saw they were all of the red color so frequently described, a much brighter red than I saw at Des Moines. I cannot speak for minute differences of color or brilliancy, because I had not intended to make the protuberances a special object of scrutiny.

I waited in vain through the few moments of total eclipse for the corona to be seen more distinctly, and observed the reappearance of sunlight under the impression that the clouds had prevented me from seeing more than a very little of the corona. But, after finishing my observations, Mr. Sprague and Mrs. Newcomb, both of whom were outside of my tent, agreed in testifying that the sky in the direction of the sun seemed quite free from clouds during the entire total phase, and that two stars were distinctly visible in the neighborhood of the sun. It is a little singular that while the two parties agree in describing the positions of the stars, their descriptions are not reconcilable with the positions of Venus or Saturn, the only bright planets in the neighborhood of the sun. I bring this forward as tending to excite suspicion that the corona is subject to very great changes of brilliancy, a suspicion, however, which can be removed or confirmed only by the observations of others. My own testimony is simply this: the corona of 1869, through a haze which rendered all but the brightest stars invisible to the naked eye, seemed to me many times more brilliant than that of 1870, seen through an atmosphere which permitted at least the brighter planets to be seen.

The first ray of returning sunlight appeared at $0^h\ 20^m\ 27^s$, chronometer. It appeared at several points of the moon's limb in such rapid succession that I could not designate an exact moment in which the crescent seemed broken up as it did 2^s before the disappearance of sunlight. During the succeeding minute I succeeded in getting three measures of the length of the crescent, but they were by no means satisfactory.

I then set the eye-piece into position for observing transits, and during the half hour following observed nine sets of transits very satisfactorily indeed. Clouds as thick as ever then intervened, but cleared away

again in time to allow of a very satisfactory set of measures of chord during the few minutes preceding the last contact, and of the observation of last contact.

The failure of the longitude determination prevents me from giving a definitive reduction of my observations. I have no knowledge of the manner in which the Admiralty longitude already quoted was determined, or whether it is sufficiently accurate for astronomical purposes. Assuming, however, that this longitude is correct, the computed and observed times of the phases, and the resulting errors of the difference of tabular longitudes of the sun and moon, will be as follows:

Phase.	Greenwich times.	Local times.	Obs. times.	Δt	$\Delta \lambda$
	h. m. s.	h. m. s.	s.	s.	"
First contact . .	22 51 38.6	22 30 15.2	13.4	− 1.8	+ 0.7
Second contact .	0 17 40.8	23 56 17.4	14.4	− 3.0	+ 1.1
Third contact . .	0 19 29.8	23 58 6.4	5.4	− 1.0	+ 0.4
Fourth contact .	1 46 47.6	1 25 24.2	18.4	− 5.8	+ 2.2

This result would indicate a correction of $+1''.1$ to the longitude of the moon derived from Peirce's tables, supposing Hansen's tables of the sun to be correct. Comparing Hansen's lunar with Le Verrier's solar tables, the relative correction will be $-6''.4$, an amount which I can scarcely believe the error of Hansen's tables have reached.

In the accompanying papers I present the observations *in extenso*, with such preliminary reductions as I have been able to make. They are as follows:

A. The observed times of contact and the measures of chords near these times, which may serve to correct the latter.

B. The observed transits of the cusps over the wires of the comet-seeker, made to determine the difference of their right ascensions. To reduce these observations completely it is necessary to know the angle which the line of motion of the instrument at any point makes with the meridian. This requires a knowledge of four constants, the errors of collimation of the two axes of the instrument, and the hour angle and polar distance of the point in the heavens toward which the polar axis of the instrument is directed. The observations for this purpose are given in C.

D. The sextant observations for latitude of station, with a summary of the resulting values of the latitude. The error of eccentricity of the sextant being uncertain, a much greater weight has been given to the results of those dates when a north and south object were both observed.

E. Sextant observations for correction of chronometer, made before the mounting of the transit, completely reduced. The result of December 16th is discordant to a degree I cannot account for; it is difficult to suppose such a change to have actually taken place in the error of the chronometer.

F. Observations for index correction of sextant.

G. Transits observed with the transit-instrument, completely reduced.

H. The observations for determining the constants pertaining to the transit-instrument.

I. Exchange of signals with Professor Hall at Malta, through the Falmouth, Gibraltar and Malta cable.

A determination of the inclination of the separate wires of the comet-seeker is still wanting for the complete reduction of the transits of cusps, and the definitive determination of the path of the center of the shadow. This cannot be done till my return, when I hope to present you with the definitive results of my observations.

It has been my agreeable duty, both in this and in my preceding reports, to inform you of the numerous facilities and courtesies extended to me by the authorities of Great Britain. I have only to add, in general terms, that nothing could exceed the cordial and friendly spirit with which the objects of our expedition were everywhere received and promoted by all the authorities and people of that country with whom it was my good fortune to come into contact. It is also just that I should acknowledge the indebtedness of the expedition to Mr. Horatio J. Sprague, United States consul at Gibraltar, for his many exertions to secure its success.

Very respectfully, your obedient servant,

SIMON NEWCOMB,
Professor of Mathematics, U. S. N.

Commodore B. F. Sands, U. S. N.,
Superintendent U. S. Naval Observatory, Washington.

A.

Observed chronometer times of contact, and distances of cusps near the times of contact.

Chronometer times.			
h.	m.	s.	
22	52	35	First contact.
22	53	55.0	Chord reaches from wires IV½ to VI.
22	54	47½	" " " " IV to VI.
22	55	31.0	" " " " III½ to VI.
22	57	50:	" " " " IV½ to VII.
22	58	58:	" " " " IV to VII.
0	18	35	The small remaining crescent broken up by the rough edge of the moon throughout its entire length.
0	18	37	The last point of sunlight vanishes.
0	20	27	Light reappears.
0	20	55	Crescent extends from wires V to XI.
0	21	11	" " " " III to XI.
0	21	29	" " " " I½ to XI.
1	40	50	Chord reaches from wires V to VIII.
1	42	16	" " " " IV½ to VII.
1	43	25	" " " " V to VII.
1	44	35½	" " " " III½ to VI.
1	45	17	" " " " IV to VI.
1	46	8	" " " " IV½ to VI.
1	46	34½	" " " " V to VI.
1	47	6½	" " " " III½ to V.
1	47	27	" " " " IV to V.
1	47	40	Last contact.

NOTE.—The measures of chord following first contact were rendered difficult and uncertain by the continual passage of flying clouds.

B.

Transits of the sun's cusps over the R. A. wires of the comet-seeker to determine the difference of their right ascension, and thence their angle of position and the angle of position of the line joining the centers of the sun and moon.

(Telescope east of axis.)

Cusp.	I.			II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
	h.	m.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
S.	23	50	59.3	. .	. .	. .	42.9	. .	28.5	. .	. .	2.5	. .
N.	23	51	20.6	. .	. .	55.5	. .	. .	52.5	. .	14.5	26.0	36.5
S.	23	54	30.5	41.0	. .	2.5	. .	. .	. .	11.0	. .	32.5	. .
N.	23	54	52.3	. .	14.0	27.0	. .	. .	23.8	. .	45.3	56.3	7.5
S.	23	58	17.5	28.3	. .	50.0	. .	23.8	48.0	59.0	. .	21.0	. .
N.	23	58	40.5	. .	3.3	. .	. .	. .	12.6	. .	34.5	45.5	56.5
S.	0	1	31.0	41.7	. .	. .	14.5	38.0	0.5	11.3	. .	. .	44.5
N.	0	1	55.0	. .	. .	29.2	. .	. .	25.5	. .	. .	59.0	10.0
S.	0	4	36.5	47.5	. .	9.2	. .	43.7	6.5	17.5	. .	. .	51.0
N.	0	5	1.5	. .	23.8	. .	. .	. .	32.8	. .	. .	6.0	17.2
S.	0	7	43.5	54.4	5.0	. .	. .	50.3	13.3	24.0	. .	. .	. .
N.	0	8	. .	20.8	31.8	. .	. .	. .	41.3	. .	3.0	14.5	26.0
S.	0	10	46.8	57.5	8.5	. .	31.0	. .	17.5	28.5	39.5	. .	2.3
N.	0	11	15.0	. .	38.0	50.0	0.8	. .	48.5	. .	11.5	23.0	35.0

The eye-piece, with the diaphragm, was now turned back 90°, to observe the length of the small remaining crescent of the sun during the minute preceding the total phase.

After the total phase, it was returned (as was supposed) accurately to its original position, and the transits of the cusps were again observed, as follows:

At

$0^h\ 23^m\ 11^s$

the line joining the cusps was parallel to the R. A. wires.

Cusp.	I.		II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
	h. m.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
S.	0 25	49.0	. .	. .	22.0	. .	. .	20.2	. .	42.0	. .	4.5
N.	0 27	. .	. .	. .	. .	. .	. .	30.5	. .	52.7	. .	15.5
S.	0 28	49.7	. .	11.5	. .	33.8	55.7	19.5	. .	41.3	. .	4.0
N.	0 29	0.2	. .	22.8	. .	45.7	9.0	32.4	. .	54.2	. .	16.8
S.	0 31	42.1	. .	3.7	. .	26.0	49.4	11.8	. .	33.6	. .	56.0
N.	0 31	54.3	. .	16.6	. .	39.5	2.5	25.5	. .	47.3	. .	9.5
S.	0 34	31.4	. .	52.9	. .	15.3	38.3	1.0	. .	23.3	. .	45.6
N.	0 34	44.2	. .	6.5	. .	29.2	52.4	15.3	. .	36.8	. .	59.5
S.	0 37	24.7	. .	46.8	. .	8.6	31.5	54.5	. .	. .	27.6	. .
N.	0 37	37.7	. .	0.5	. .	23.0	46.3	9.2	. .	. .	41.9	. .
S.	0 40	8.7	. .	30.3	. .	52.5	15.3	38.1	. .	0.0	. .	22.0
N.	0 40	22.0	. .	44.0	. .	6.6	29.8	52.1	. .	14.0	. .	36.2
S.	0 42	50.5	. .	12.4	. .	34.5	57.5	20.2	. .	41.9	. .	4.5
N.	0 43	4.2	. .	26.4	. .	49.1	12.0	34.7	. .	56.4	. .	18.5
S.	0 45	51.5	. .	12.9	. .	34.9	57.8	20.9	. .	42.0	. .	5.0
N.	0 46	4.6	. .	27.2	. .	49.5	12.5	35.4	. .	57.0	. .	19.4
S.	0 48	41.2	. .	2.8	. .	25.0	47.5	10.5	. .	32.0	. .	54.5
N.	0 48	54.5	. .	16.8	. .	39.0	2.0	25.0	. .	46.2	. .	8.5

It was now found that after the total phase the eye-piece was not returned accurately to its original position. While, before the total phase, the middle R. A. wire was very nearly parallel to the line of motion of the telescope in N. P. D., it was now found, by observation on a distant terrestrial mark, that the top of the middle wire deviated to the east by an amount which throughout the breadth of the field (about 1°) amounted to $\frac{1}{9}$ the distance of the closer wires, or about 17″, making the change of inclination about 0° 16′. The probable error of this estimate is about $\frac{1}{6}$ its amount.

C.

Readings of circles when telescope is pointed on terrestrial marks in reversed positions of the instrument, made to determine the collimation errors of the telescope and the declination axis, and the index error of the declination-circle.

Mark.	Readings of declination—Verniers.		Readings of R. A.—Verniers.		Mean Vernier.	
	I.	II.	I.	II.	Dec.	R. A.
	° ′	° ′	h. m. s.	h. m. s.	° ′	h. m. s.
First mark	314 58	135 47	9 47 22	21 48 12	315 22	9 47 47
Tel. reversed . . .	224 30	45 24	21 47 44	9 47 24	224 57	21 47 34
Second mark . . .	308 0	128 56	10 17 2	22 18 0	308 28	10 17 31
Tel. reversed . . .	231 18	52 16	22 17 46	10 18 18	231 47	22 18 2
Third mark	8 22	189 15	18 25 18	6 25 42	8 48	18 25.30
Tel. reversed . . .	171 0	351 52	6 26 26	18 27 22	171 26	6 26 54

These readings give, for the index error e of the declination-circle.

First mark.	$2e = -19'$
Second mark.	$2e = -15'$
Third mark.	$2e = -14'$
Mean.	$e = -\ 8'$

The following readings of the declination-circle, when the telescope was pointed on the center of the sun, were made to determine the error in the direction of the polar axis of the instrument:

Date.	Chronometer times.		Sun's hour-angle.			Readings of Verniers. I.		Readings of Verniers. II.		Telescope.	Resulting distance of pole of instrument from sun.		Pole of instrument beyond pole of the earth.	
	h.	m.		h.	m.	°	′	°	′		°	′		′
December 21	22	24	−	1	57	336	15	157	4	E.	113	28	+	2
	23	16	−	1	4	336	5	156	57	E.	113	37	−	11
December 22	1	0	+	0	39	335	52	156	44	E.	113	50	−	24
	1	5	+	0	44	203	30	24	23	W.	113	49	−	23
	3	2	+	2	41	335	47	156	41	E.	113	54	−	28

From these five observations it is concluded that the pole of the instrument was directed to a point 18′ below and 25′ east from the pole of the heavens.

Rigorously the preceding observations suffice for the complete determination of the angle which the line of motion of the instrument in declination makes with the meridian at any point. But, to have a check on the correctness of the results, several transits of pairs of stars, near in R. A. but more distant in declination, were observed over the middle wire of the telescope, the pointing of the latter in R. A. remaining unchanged

between the transits ot each pair. These observations were made on the night preceding the eclipse, and are as follows:

	Chronometer. h.	m.	s.
Transit of β Ceti over middle wire	7	41	31
Transit of ϵ Piscium, telescope being moved in declination only	8	0	19.5
Difference of mean times of transit		18	48.5
Difference of sidereal times of transit		18	51.5
Difference of right ascensions of stars		19	8.4
Amount by which the southern star passes too late			16.9
Transit of γ Geminorum	10	9	18.5
Transit of Sirius	10	19	6.0
Difference of right ascensions		9	12.4
Southern star too late			36.6
Transit of α Andromedæ	10	27	42.5
Transit of γ Pegasi	10	32	14.0
Difference of right ascensions		4	52.3
Southern star too early			20.0
Transit of α Andromedæ	10	35	17
Transit of γ Pegasi	10	39	47
Southern star too early			21.5

D.

Observations with Sextant for Latitude.

DECEMBER 15, 1870.—Double altitudes of the sun's limbs observed at the telegraph office. Index correction of sextant, + 20″. Temperature 65°. Chronometer time of apparent noon, $0^h\ 17^m\ 36^s$.

Chronometer.	Limb.	Reading of sextant for double alt.	Resulting mer. alt. of center.	Result.	
h. m. s.		° ′ ″	° ′ ″		° ′ ″
0 22 30	L.	60 37 0	30 33 56	Mean observed meridian altitude	30 34 4
0 24 30	L.	60 35 40	30 33 57	☉'s south declination	23 17 24
0 25 30	U.	61 40 25	30 34 8	Altitude of equator	53 51 35
0 26 30	U.	61 39 30	30 34 12	Latitude	36 8 25
0 27 30	U.	61 38 50	30 34 19	Reduction to station	— 1 28
0 28 30	L.	60 31 30	30 33 50	Latitude of station	36 6 57

Double altitudes of Polaris. Index correction, + 30″. Temperature, 57°.

Chronometer.	Limb.	Reading of sextant for double alt.	Resulting mer. alt. of center.	Result.	
h. m. s.		° ′ ″	° ′ ″		h. m. s.
10 10 30	. .	74 35 30	. . .	Sid. time of mean of observations	3 31 0
10 14 30	. .	74 35 0	. . .	Hour angle	2 19 2
					° ′ ″
10 16 40	. .	74 33 10	. . .	Latitude	36 8 25
10 17 50	. .	74 32 30	. . .	Latitude of station	36 6 57
10 19 20	. .	74 31 30	. . .		

DECEMBER 20.—Double altitudes of sun observed at Buena Vista, (eclipse station.) Index correction, + 18″. Chronometer time of apparent noon, $0^h\ 20^m\ 12^s$. Refraction, 1′ 41″ for upper, and 1′ 44″ for lower limb.

Chronometer.	Limb.	Reading of sextant for double alt.	Resulting mer. alt. of center.	Result.
h. m. s.		° ′ ″	° ′ ″	° ′ ″
0 24 53	U.	61 27 10	30 26 22	Mean observed meridian altitude.. 30 26 21
0 26 25	U.	61 26 20	30 26 25	⊙'s south declination....... 23 26 47
0 27 40	U.	61 25 15	30 26 22	Altitude of equator........ 53 53 16
0 28 45	L.	60 19 0	30 26 19	Latitude of station........ 36 6 44
0 29 37	L.	60 18 10	30 26 16	
0 30 37	L.	60 17 10	30 26 22	

DECEMBER 26.—Double altitudes of α Ceti and Polaris observed at the house of the American consul. Index correction, + 43″. Correction chronometer for local mean time, —$22^m\ 23^s$.

α Ceti.

Chronometer.	Reading of sextant for double alt.	Resulting latitude.		
h. m. s.	° ′ ″	° ′ ″		° ′ ″
7 5 20	69 40 35	36 7 52		
7 8 25	69 30 15	36 7 55	Mean latitude	36 7 41
7 10 28	69 23 15	36 7 37	Reduction to station	— 1 8
7 12 8	69 16 45	36 7 35	Latitude of station	36 6 33
7 13 35	69 11 10	36 7 27		

Polaris.

Chronometer.	Reading of sextant for double alt.	Resulting latitude.		
7 18 50	75 2 15	36 7 43		° ′ ″
7 27 5	75 2 45	36 8 15	Mean lat., giving half wt. to first obs.	36 8 12
7 29 5	75 2 50		Reduction to station	— 1 8
7 30 40	75 2 30		Latitude of station	36 7 4
7 33 0	75 3 10			
7 36 50	75 3 0			

Summary of Results for Latitude of Station.

INDIVIDUAL RESULTS.

		°	′	″
December 15.	Sun,	36	6	57
December 15.	Polaris,	36	6	57
December 20.	Sun,	36	6	44
December 26.	α Ceti,	36	6	33
December 26.	Polaris,	36	7	4

MEAN BY DATES.

	°	′	″	
December 15.	36	6	57	with weight 3
December 20.			44	with weight 1
December 26.			49	with weight 4
Mean,	36	6	51 ± 4	

E.—*Sextant Observations for Correction of Chronometer.*

Date and station.	Object.	Limb.	Chronometer time.	Sextant reading for double alt.	Geocentric altitude of center.	Correction of chronom.	Remarks.
			h. m. s.	° ′ ″	° ′ ″	m. s.	
Dec. 14.9,	Sun . .	U.	23 10 43	57 37 20	28 30 54	− 22 6	Observations very uncertain,
Telegraph		U.	23 14 25	58 2 45	28 43 37	13	owing to bad definition of the
Office.		L.	23 15 25	57 5 20	28 47 29	5	sun's limb in the haze.
		L.	23 17 30	57 18 30	28 54 4	10	Mean correction, $-22^m\ 8^s.5$.
Dec. 15,	Sun . .	U.	3 56 9	23 19 0	11 19 10	− 22 16.3	Temperature, 68°; index, +40″.
Telegraph		U.	3 57 29.5	22 54 15	11 6 45	16.3	Mean correction, $-22^m\ 16^s.3$.
Office.		U.	3 58 30.5	22 35 50	10 57 27	16.3	
		U.	3 59 38	22 15 10	10 47 1	17.3	
		U.	4 0 34	21 57 35	10 38 9	16.3	
		U.	4 5 13	20 31 20	9 54 45	18.8	
		L.	4 10 2	17 54 10	9 8 3	13.0	
	α Lyræ .	.	6 19 30	63 45 0	31 51 14	− 22 18.0	Temperature, 60°; index, +30″.
			6 24 10	62 3 20	31 0 22	14.8	Mean correction, $-22^m\ 16^s.1$.
			6 26 24	61 15 55	30 36 36	16.1	
			6 29 15	60 14 50	30 6 2	15.6	
	Jupiter .	.	9 54 37	117 7 30	58 33 25	− 22 16.4	Temperature, 57°.
			9 58 54	118 46 45	59 23 4	16.1	Mean correction, $-22^m\ 16^s.9$.
			10 0 25	119 21 15	59 40 18	19.4	
			10 1 45	119 53 10	59 56 16	15.6	
			10 2 56	120 19 45	60 9 35	16.8	
			10 4 4	120 46 15	60 22 48	17.0	
			10 5 12	121 12 10	60 35 50	17.2	
	α Androm.	.	10 29 54	85 34 50	42 46 38	− 22 16.0	Mean correction, $-22^m\ 16^s.8$.
			10 31 51	84 48 30	42 28 28	17.6	
Dec. 16,	α Lyræ .	.	7 54 9.5	30 0 20	14 56 50	− 22 14.2	Temperature, 57°; index, +25″.
Telegraph			7 56 44	29 10 50	14 31 59	14.0	Mean correction, $-22^m\ 14^s.6$.
Office.			7 59 50	28 11 35	14 2 14	14.4	
			8 1 39.5	27 37 0	13 44 52	14.8	
			8 4 36	26 41 25	13 16 57	15.7	
Dec. 20,	Sun . .	U.	3 50 59	25 28 10	12 23 56	− 22 19.8	Temperature, 59°; index, +18″.
Eclipse		U.	3 56 58	23 39 25	11 29 15	19.2	Mean correction, $-22^m\ 19^s.1$.
Station.		U.	3 59 25.5	22 54 5	11 6 27	18.3	

F.—*Observations for Index Correction of Sextant.*

Each result is generally the mean of two observations.

Date.	Object.	Readings "Off" arc.	Readings "On" arc.	Correction.
d. h.		° ′ ″	° ′ ″	″
December 14, 23	Sun . .	359 27 0	0 32 50	+ 5
15, 1	Sun . .	359 26 5	0 33 15	+ 20
4	Tower*.	359 47 25	0 10 42	+ 40
11	Jupiter .	359 59 5	359 55 55	+ 30
20 0	Sun . .	359 27 12	0 32 12	+ 18
26 7	Moon .	359 27 58	0 30 37	+ 42

* Measures of the width of the signal tower, about 4,000 feet distant. Correction for parallax — 16″.

G.—*Transits observed with the Transit Instrument at the Eclipse*

Number.	Date.	Object.	Position of clamp.	Seconds of transit over wires.							Resulting time of transit over middle wire.			Level employed.	Level indication.
				1.	2.	3.	4.	5.	6.	7.					
	1870.			s.	s.	s.	s.	s.	s.	s.	h.	m.	s.		d.
1	Dec. 20	Polaris	W.	. .	. .	. .	30.0	3.0	. .	. .	7	37	30.0	A	2.6 E.
2		o Piscium	W.	. .	. .	46.8	. .	29.5	50.7	11.3	8	4	7.6	A	3.0 E.
3		50 Cassiopeæ . . .	W.	. .	. .	52.1	1.0	9.5	. .	. .	8	17	59.9	A	8.6 E.
4		ξ^1 Ceti	W.	. .	. .	. .	39.5	1.0	21.7	42.5	8	31	39.2	A	10.4 E.
5		ι Cassiopeæ . . .	W.	. .	. .	2.3	55.5	50.5	44.0	36.5	8	43	55.6	A	6.0 E.
6		γ Ceti	E.	. .	. .	. .	. .	22.0	43.7	5.0	9	2	1.4	.	8.5 E.
7		α Ceti	E.	50.0	10.5	31.8	53.7	14.5	35.5	57.3	9	20	53.4	.	8.0 E.
8		α Persei	E.	46.0	9.0	51.3	24.5	56.3	28.5	2.0	9	40	24.4	.	3.0 W.
9	21	β Arietis	.	57.7	. .	. .	. .	27.5	. .	13.0	8	9	5.2	.	2.5 E.
10		α Arietis	.	. .	40.7	4.0	27.8	50.0	13.0	36.3	8	21	27.4	A	6.1 E.
11		ι Cassiopeæ . . .	.	. .	18.5	11.3	7.0	59.7	53.7	47.7	8	40	6.8	.	2.9 E.
12		5 Ursæ Minoris, S. P. .	.	. .	. .	. .	. .	26.0	55.3	21.0	8	48	55.0	.	4.7 W.
13		α Ceti	W.	50.5	. .	22.4	. .	. .	35.8	56.3	9	16	53.3	.	4.3 W.
14		ζ Arietis	W.	42.0	. .	28.3	. .	13.5	. .	57.5	9	28	50.2	.	4.2 W.
15		α Persei	W.	. .	. .	. .	. .	5.5	37.7	9.3	9	36	32.2	.	7.9 E.
16	22	α Persei	E.	. .	. .	. .	. .	. .	38.0	11.0	9	32	33.4	B	18.2 W.
17		η Tauri	E.	. .	. .	47.5	10.5	33.5	. .	20.3	9	57	10.8	A	6.4 W.
18		γ Eridani	E.	13.5	34.5	56.3	18.7	39.7	1.7	23.8	10	9	18.5	A	4.1 W.
19		γ Tauri	W.	. .	. .	. .	40.5	3.0	24.7	46.3	10	29	40.6	A	18.5 W.
20		α Tauri	W.	. .	58.3	21.0	42.8	5.2	27.0	48.6	10	45	42.6	A	4.2 W.
21		ι Aurigæ	W.	30.5	55.5	21.2	46.0	11.8	37.0	1.2	11	5	46.0	A	9.4 W.
22		ε Ursæ Minoris, S. P. .	W.	. .	. .	. .	41.0	. .	. .	. .	11	15	41.0	A	2.5 W.
23	23	α Lyræ	W.	8.5	36.2	2.5	28.8	56.6	23.4	49.6	0	47	29.1	A	10.8 E.

NOTES.

1. The two wires are discordant by 30^s, and the observation is not used.

9. Before this observation the transit wires were found far from vertical, though they had been carefully adjusted on the 17th. They were readjusted, and, on examining the collimation by reversal on a distant object, the middle wire was found too near the clamp side of the instrument by an amount estimated at $0^s.10$ or $0^s.12$.

8, 19. Before each of these observations the azimuth was accidentally changed by moving the azimuth-screw.

Station to determine the error of the Chronometer on Local Time.

Number.	Correction for— Collimation.	Correction for— Level.	Minutes and seconds of transit over a vertical circle.	Computed mean time of transit over meridian.	Difference.	Coefficient of azimuth.	Adopted azimuth.	Correction of chronometer.
	s.	s.	m. s.	h. m. s.	m. s.		s.	m. s.
1	0.00	− 4.0	37 26.0	7 15 12.0	− 22 14.0	− 32.6	+ 0.50	− 22 30:
2	0.00	− 0.1	4 7.5	7 41 46.9	20.6	+ 0.47	. .	20.4
3	0.00	− 1.5	17 58.4	7 55 38.7	19.7	− 1.8	. .	20.6
4	0.00	− 0.6	31 38.6	8 9 17.2	21.4	+ 0.47	. .	21.2
5	0.00	− 0.9	43 54.7	8 21 34.3	20.4	− 1.3	. .	21.0
6	0.00	− 0.5	2 0.9	8 39 39.6	21.3	+ 0.55	. .	21.0
7	0.00	− 0.5	20 52.9	8 58 31.8	21.1	+ 0.55	. .	20.8
8	0.00	+ 0.3	40 24.7	9 18 4.0	20.7	− 0.35	. .	20.9
9	− 0.32	− 0.17	9 4.7	7 46 45.5	19.2	+ 0.29	− 5.00	20.7
10	− 0.32	− 0.42	21 26.7	7 59 6.8	19.9	+ 0.25	. .	21.1
11	− 0.5	− 0.4	40 5.9	8 17 38.3	27.6	− 1.30	. .	21.1
12	+ 1.2	− 0.5	48 55.7	8 26 54.2	1.5	+ 3.90	. .	21.0
13	+ 0.30	+ 0.23	16 53.9	8 54 35.9	18.0	+ 0.55	− 6.30	21.5
14	+ 0.32	+ 0.28	28 50.8	9 6 31.1	19.7	+ 0.29	. .	21.5
15	+ 0.45	− 0.79	36 31.8	9 14 8.1	23.7	− 0.36	. .	21.4
16	− 0.45	+ 1.55	32 34.5	9 10 12.2	22.3	− 0.36	− 2.90	21.3
17	− 0.32	+ 0.45	57 11.0	9 34 49.7	21.3	+ 0.24	. .	22.0
18	− 0.31	+ 0.18	9 18.4	9 46 59.5	18.9	+ 0.79	. .	21.2
19	+ 0.32	+ 1.41	29 42.3	10 7 22.6	19.7	+ 0.36	− 6.30	22.0
20	+ 0.32	+ 0.30	45 43.2	10 23 24.0	19.2	+ 0.35	. .	21.4
21	+ 0.36	+ 0.75	5 47.1	10 43 25.2	21.9	+ 0.06	. .	22.3
22	− 2.2	− 0.6	15 38.2	10 53 56.5	− 21 41.7	+ 6.50	. .	22.6
23	+ 0.39	− 0.87	47 28.6	0 25 6.2	− 22 22.4	− 0.05	. .	22.7

NOTES.

22. On the following morning the collimation was examined by reversal, and the middle wire found too near the clamp end of the axis by $0^{r}.031$ of the azimuth-screw. The observation was made in sunshine. The results for chronometer error seem to show that this collimation is fictitious; but, as the error will be eliminated from the mean of observations made in both positions of the instrument, I have made no change in the result.

H.

Determination of Constants pertaining to the Transit-Instrument.

Calling wire I that nearest the clamp end of the axis, the eight transits observed over both wires, I and IV, were taken, and the observed intervals separately reduced to the equator by multiplying them by cos δ. The same thing was done with the ten transits observed over wires IV and VII. The results were:

$$\begin{aligned} \text{VII}-\text{IV} &= \overset{s.}{63.28} \\ \text{IV}-\text{I} &= 63.34 \\ \text{VII}-\text{I} &= 126.62 \end{aligned}$$

The intermediate wires were determined by means ot the azimuth-screw of the instrument. The latter being pointed on a distant mark, the readings of the screw for coincidence of the several wires with the mark were as follows:

Wires.	Microm.	Intervals.	Intervals in time.	Reduction of each wire to IV.
	r.	r.	s.	s.
I.	20.800	1.620	21.56	+ 63.54
II.	19.180	1.590	21.17	+ 41.98
III.	17.596	1.563	20.81	+ 20.81
IV.	16.033	1.627	21.67	0.00
V.	14.406	1.584	21.09	− 21.67
VI.	12.822	1.528	20.34	− 42.70
VII.	11.294			− 63.10

From the first and last of these readings is concluded:

$$\begin{aligned} \text{VII}-\text{I} = 9^r.512 &= 126^s.62 \\ 1^r &= 13^s.312 \end{aligned}$$

and the intervals and reductions to middle wire are thence deduced.

To find the value of one revolution of the level-screw, the instrument was fastened in its Y's by an elastic cord, and the stand was then tipped over so that the level-screw was horizontal. The following three intervals were then determined in the same way with that employed in investigating the azimuth screw:

$$\begin{aligned} \text{II}-\text{I} &= 1^r.590: \text{ difference from azimuth screw} = -0^r.030 \\ \text{III}-\text{II} &= 1^r.569: \text{ difference from azimuth screw} = -0^r.021 \\ \text{IV}-\text{III} &= 1^r.521: \text{ difference from azimuth screw} = -0^r.042 \end{aligned}$$

From this is concluded,

$$\begin{aligned} 4^r.680 &= 63^s.54 \\ 1^r &= 13^s.58 \end{aligned}$$

The Spirit-Levels.

These were put upon the axis of the instrument in succession, and their bubbles were read in different positions of the level-screw, as follows:

Level screw.	Level B.		Level screw.	Level A.	
	W.	E.		W.	E.
r.	*d.*	*d.*	*r.*	*d.*	*d.*
.109	28.0	77.0	.235	55.5	82.0
.210	45.5	58.5	.350	79.0	57.8
.300	60.0	43.0	.250	56.0	80.0
.100	20.0	83.5	.370	81.5	55.0
.300	57.0	45.5	.240	51.5	84.0
.400	74.0	28.0	.400	85.5	49.5
.100	15.0	88.0			

Having regard to the value just found for one revolution of the level-screw, it is concluded that

One division of level A $= 0^s.065$
One division of level B $= 0^s.072$

I.

Exchange of Signals with Professor Hall at Malta, through the Falmouth, Gibraltar and Malta Cable.

December 15.

A signal was sent every fifteen seconds from $4^h\ 45^m\ 0^s$ to $4^h\ 50^m\ 0^s$, chronometer time, but the signal which should have been sent at $4^h\ 49^m\ 45^s$ was half a second late.

Signals from Malta were received at the following times:

h.	m.	s.	h.	m.	s.
4	52	47.1	4	55	2.2
	53	2.4			17.3
		17.4			32.4
		32.4			47.3
		47.3		56	2.5
	54	2.5			17.3
		17.3			32.2
		32.3			47.4
		47.3		57	2.4
					17.4

Next morning, December 16, civil time, signals were sent to Malta every fifteen seconds from $23^h\ 32^m\ 0^s$ to $23^h\ 37^m\ 0^s$.

Signals from Malta were received as follows:

h.	m.	s.	h.	m.	s.
23	39	18.7:	23	42	3.2
		32.7:			18.0
		48.0:			33.0
	40	3.0			48.1
		17.9:		43	3.2
		33.0			18.3
		48.1			33.2
	41	3.2			48.1
		18.2		44	3.0
		33.2			18.3
		48.1			

NOTE.—The signals were sent by pressing a key simultaneously with the proper beat of the chronometer. They were received by having an operator strike a key as soon as he saw the motion of the image reflected from the mirror of the galvanometer. The time of this stroke was noted by the observer at the chronometer.

REPORT

OF

PROFESSOR ASAPH HALL, U. S. N.

REPORT OF PROFESSOR HALL, U. S. N.

UNITED STATES NAVAL OBSERVATORY, *Washington, February* 27, 1871.

SIR: I have the honor to submit the following report of my observations of the solar eclipse of December 22, 1870.

I left New York November 2, on the Cunard steamship China, and, arriving at Liverpool November 13, proceeded thence by the way of London to Southampton, and from that port by the steamship Poonah, of the Peninsular and Oriental Line, to Malta, and from Malta by the Florio steamer to Syracuse; arriving at Syracuse December 8. I returned to Malta December 12, and remained there four days for the purpose of exchanging telegraphic signals for longitude with Professor Newcomb at Gibraltar, and with Professor Harkness at Syracuse.

We left Syracuse the day after the eclipse, and, passing through Italy and Central Europe, I returned to England by the way of Ostend and Dover. Leaving Liverpool January 21, I arrived at Washington February 3, 1871.

I wish to express my sincere thanks to Signor Nunzio Stella, the American consular agent, and to the civil and military authorities of Syracuse, for their kind attentions to our party, and for the facilities afforded us. I am indebted also to Signor Bisani, the English consular agent, for his assistance.

At Malta I was under great obligations to Mr. Lyell T. Adams, our consul, and to Mr. B. Smith and Mr. Edward Rosenbusch, superintendents of the telegraph offices in Malta. It was only through the energy and skill of Mr. Rosenbusch that we were able to make the telegraphic connections between Malta and Syracuse. I have to offer my thanks to Messrs. Pisani, Portelli, Fauqueir, and other gentlemen connected with the telegraph offices, for the assistance rendered me in exchanging the signals. To Mr. Pisani I am also indebted for assistance in my time observations. I am under special obligations to Captain G. L. Tupman, of the Royal Marine Artillery, who assisted me in many of my sextant observations, and who furnished me with much local information. M. Berthet, optician at Valetta, very kindly allowed me the use of his fine transit-instrument. The whole party is much indebted to the Messrs. Negus, of New York, who furnished us with excellent chronometers.

THE ECLIPSE.

My observing station in Syracuse was on the "Bastione San Filippo," a little north of the gate "Prima Porta Terra." My telescope was a comet-seeker by Ploessl, with a 3¾-inch object-glass and a magnifying power of about fifty. The following are my observations of the times of contact and the bisections of solar spots. The times observed are those of the chronometer Negus 1228, and were observed with a dark glass at the eye-piece except those of the second and third contacts, or the beginning and end of total eclipse, which were observed without the shade:

Object.	Ch. Negus 1228.	Chron. corr.	Local M. T.	Notes.
	h. m. s.	h. m. s.	h. m. s.	
First contact . . .	11 37 35.0	+ 1 0 38.0	0 38 13.0	Fair.
Spot *d*	11 43 16.0	1 0 38.0	0 43 54.0	Fair.
Spot *f*	0 0 51.0	1 0 38.0	1 1 29.0	Fair.
Spot *h*	0 12 6.0	1 0 38.0	1 12 44.0	Good.
Spot *m*	0 33 27.0	1 0 38.0	1 34 5.0	Good.
Spot *n*	0 34 46.0	1 0 38.0	1 35 24.0	Good.
Spot o_1	0 37 37.0	1 0 38.0	1 38 15.0	Fair.
Spot o_2	0 38 5.0	1 0 38.0	1 38 43.0	Fair.
Second contact . .	1 2 17.5	1 0 38.0	2 2 55.5	Good.
Third contact . . .	1 4 0.0	1 0 38.0	2 4 38.0	Poor.
Fourth contact . .	2 21 20.5	+ 1 0 38.0	3 21 58.5	Fair.

The annexed diagram of the solar spots was made about an hour before the beginning of the eclipse, and will serve to identify the spots observed. The observed times of contact agree very closely with those computed from the data of the American Ephemeris, the longitude of Syracuse being assumed as $-6^h\ 9^m\ 25^s.6$; but as our attempt to determine the longitude of Syracuse from Greenwich was unsuccessful, on account of a break in the submarine cable between Gibraltar and England, no accurate comparison with the tables can be made. Assuming, however, that the longitude of Gibraltar is tolerably well known, our telegraphic connection with that point enables us to determine the longitude of our observing station at Syracuse. In this way Professor Harkness finds for the longitude east of Washington

$$6^h\ 9^m\ 27^s.8$$

By combining the results of all the sextant observations, Professor Harkness has deduced as the most probable value of the latitude of our station

$$\varphi = +37^\circ\ 3'\ 52''.6 \pm 2''.98$$

I have adopted therefore

$$\varphi = +37^\circ\ 3'\ 53''$$
$$\lambda = -6^h\ 9^m\ 27^s.8$$

and a computation from the data of the American Ephemeris gives the following times of contact:

Phase.	Computed times.			Observed times.			Δt.
	h.	m.	s.	h.	m.	s.	s.
First contact . . .	0	38	19.2	0	38	13.0	+ 6.2
Second contact . .	2	3	5.1	2	2	55.5	+ 9.6
Third contact . . .	2	4	46.1	2	4	38.0	+ 8.1
Fourth contact . .	3	22	8.0	3	21	58.5	+ 9.5

The following differential equations will serve for computing changes in the times of contact produced by small changes in the position of the observing station:

$$dt = -0.014\,d\varphi - 1.525\,d\lambda, \text{ first contact,}$$
$$dt = -0.014\,d\varphi - 1.509\,d\lambda, \text{ second contact,}$$
$$dt = -0.014\,d\varphi - 1.423\,d\lambda, \text{ third contact,}$$
$$dt = -0.014\,d\varphi - 1.300\,d\lambda, \text{ fourth contact,}$$

$d\varphi$ being expressed in seconds of arc, and $d\lambda$ in seconds of time. The value of φ is supposed to increase positively toward the north and that of λ toward the west.

The times of contact computed by Signor Agnello, of the Palermo Obervatory, are on an average 25 seconds earlier than those which I have computed, except the time of first contact, which is 88 seconds later, evidently a misprint or the result of some error of computation. Signor Agnello's data is that of the English Nautical Almanac.

My chief purpose during the total eclipse was to observe the structure of the corona, with special reference to the curved and radiating lines seen in previous eclipses, but the condition of the sky was such that this observation was unsatisfactory. During the last quarter of an hour of the first partial phase it appeared hopeless that the total eclipse would be visible, the sun being covered by a thick cloud. This cloud, however, had a slow motion upward and toward the east, and a few minutes before totality the nar-

row crescent of the sun appeared through the clouds. On account of these clouds I was able to take off my colored glass shade and watch the disappearance of the sun without any protection or inconvenience to the eye. The apparent diameters of the sun and moon being nearly equal, the bright crescent became extremely long and narrow, and broke up into bits and fragments, but I noticed no color nor anything remarkable before the disappearance of the last long, thin remnant. After recording my observed time of the beginning of total eclipse I pointed the telescope to the east limb of the moon and swept around toward the south back to the starting point. I should not estimate the extent of the corona to be more than five or ten minutes from the limb of the moon, but the clouds make this estimate quite uncertain; and with regard to the form or outline of the corona it could not, I think, be observed with accuracy. The appearance of the corona in the telescope was that of a soft, white, diffused light. There was very little appearance of the radiating lines shown in many pictures, and I saw no curved streamers. Near the southwestern point of the moon there was apparently a deep opening in the corona, reaching nearly to the limb of the moon, but on account of the clouds this opening was very indistinct.

After sweeping around the moon I pointed the telescope on one of the large protuberances near the eastern limb of the moon, but could see nothing of the spotted or cellular appearance seen by Professor William A. Rogers in the eclipse of August 7, 1869. The protuberances, which were very numerous, were uniformly of a dull pink color. Then having some fifteen or twenty seconds to spare, I looked at the eclipse with the naked eye. The moon was still covered with the light and shifting clouds, but as they were rising and passing toward the east the lower and southwestern part of the moon was much the clearer. At this point the corona was quite bright, and here several delicate streamers shot down to the distance of eight or ten degrees. There was no color, and to the naked eye the corona appeared, as in the telescope, of a soft, white light. Putting my eye back to the telescope I observed the first reappearance of the sun through a deep notch in the moon's limb. This a little disturbed me and made my observation of the end of totality somewhat uncertain.

The darkness during total eclipse was much less than during the eclipse of August, 1869. As the totality approached it became quite cold, and a strong wind arose, but as my telescope had a solid, firm mounting, the wind gave me no trouble. I did not see the planet Saturn, which was a little north of the moon, but my attention was not specially directed to the discovery of the planet.

The general appearance of the total eclipse was something as follows: The black moon in the center surrounded with a narrow rim of bright light a quarter or half a minute in thickness. Above this rim rose the dull pink-colored protuberances, and beyond these extended the white corona, the whole making a very beautiful sight. I refrain from attempting to make any picture of the eclipse. On account of the suddenness, the beauty and grandeur of the phenomena displayed, it is very difficult to make a correct picture by hand-sketching; and so much must the memory be relied on, and so great is the opportunity for the play of the imagination, that I can have but little faith in such pictures. Photography appears to furnish the only means of making a truthful picture. At Syracuse we were fortunate in having the companionship of three English observers, Messrs. Brothers and Fryer, of Manchester, and Mr. Griffith, of Harrow. Messrs. Brothers and Fryer obtained several photographs of the total eclipse, and one which was understood to be very satisfactory.

At the instant of the beginning of total eclipse I noticed in the telescope an appearance that it may be worth while to describe. The protuberances darted quickly into view, and there was a flashing back of the sunlight, and an apparent mingling of red and white light that was very striking. The appearance was somewhat like that given by Mr. Gilman in his picture of the eclipse of 1869, but it was, I think, an optical illusion, for after recording my time and putting my eye again to the telescope the appearance was entirely gone.

With regard to the long streamers seen near the end of totality, I had the impression when seeing them that they were not of the corona proper, but were produced in the earth's atmosphere. This impression was caused, perhaps, by the proximity of the clouds, and by the resemblance of the streamers to the phenomenon commonly spoken of as the "sun's drawing water," only the streamers were much more delicate and more like what we see sometimes in our atmosphere on a hazy day.

SEXTANT OBSERVATIONS.

I give below the observations for time and latitude made at Malta and Syracuse with the Pistor & Martins patent sextant No. 107. The altitudes were observed by myself, and the times at Malta by Captain Tupman and Mr. Pisani; at Syracuse by Professor Eastman, Captain Tupman, and myself. In the column of dates I have placed the initials of the observers. It should be stated that the observations at Malta, until December 15, were made with the low power, as the colored shade had become so firmly fixed to this telescope during the transportation of the instruments that I did not succeed in removing it until the evening of December 14.

Date.	Chronom. 1228.			Sextant R.			Corr. chronom. and latitude.			Results.
										MALTA.
1870.	h.	m.	s.	°	′	″	h.	m.	s.	
Dec. 12.9	7	58	40.5	34	29	0	+ 0	57	30.0	
H. T.	7	59	37.7	34	44	30			29.5	$dt = +0.1250\ dh + 0.0941\ d\varphi$
	8	0	25.6	34	57	40			30.1	h. m. s. s.
	8	1	45.2	36	23	10			26.3	$\Delta c = +0$ 57 29.0 ± 0.28
	8	3	47.5	36	56	40			28.6	Red. = + 0.6
	8	5	8.1	37	18	30			29.3	
	8	6	29.2	37	39	30			27.5	
	8	7	44.4	38	0	50			31.0	
	8	8	22.2	38	10	10			30.5	
	8	9	35.2	37	23	50			28.7	
	8	12	46.1	38	13	40			29.0	
	8	13	37.7	38	26	20			26.9	
							°	′	″	° ′ ″
Dec. 13.0	10	58	43	61	21	30	+35	52	90	$\varphi = +35$ 52 55 ± 3.0
H. T.	10	59	15.5	61	22	50			46	
	10	59	49	61	22	10			62	
	11	0	32	61	21	20			78	
	11	1	14.5	62	27	40			31	
	11	1	49.5	62	27	0			41	
	11	2	27.2	62	26	40			41	
	11	3	12	62	25	30			60	
	11	3	51.5	62	25	10			56	
	11	4	24.2	62	24	40			56	
	11	5	0	62	24	20			51	
	11	5	34.5	62	23	30			59	
	11	6	8.5	61	17	40			66	
	11	8	10	61	15	50			49	
	11	8	41.2	61	15	10			50	
	11	9	7.2	61	14	30			50	
							h.	m.	s.	
Dec. 13.9	7	42	48.5	30	52	0	+ 0	57	29.8	$dt = +0.1165\ dh + 0.0825\ d\varphi$
H. T.	7	43	21.7	31	1	50			31.0	h. m. s. s.
	7	43	50.6	31	9	40			29.2	$\Delta c = +0$ 57 28.4 ± 0.39
	7	44	36.2	30	17	10			27.0	
	7	45	15.3	30	28	10			26.4	
	7	45	46.5	30	37	0			26.0	
	7	46	39.0	30	52	10			26.7	
	7	47	25.6	31	5	20			26.3	
	7	48	10.5	31	18	40			28.5	
	7	48	47.8	32	34	0			27.8	
	7	49	22.2	32	44	50			31.8	
	7	49	49.2	32	52	10			30.7	

Sextant Observations—Continued.

Date.	Chronom. 1228.			Sextant R.			Corr. chronom. and latitude.			Results.
1870.	h.	m.	s.	°	′	″	°	′	″	MALTA.
Dec. 14.0	5	53	52	61	9	20	+35	53	66	Times by Frodsham watch 1915:
H. P.	5	55	12	61	8	0			67	h. m. s.
	5	55	46	61	8	10			40	Chr. 1228, 11 27 0
	5	56	29	62	12	10			54	Fr. 1915, 6 15 28.4
	5	57	1	62	11	40			49	° ′ ″ ″
	5	57	30	62	11	20			41	$\phi=+35$ 54 0 ± 2.3
	5	58	23	62	8	50			77	
	5	58	45	62	8	50			64	
	5	59	18	62	8	20			55	
	5	59	57	61	1	40			70	
	6	0	29	61	1	0			65	
	6	0	56	61	0	0			72	
							h.	m.	s.	
Dec. 14.1	1	43	30	37	34	10	+0	57	26.1	$dt=-0.1222\,dh-0.0903\,d\phi$
H. P.	1	44	13	37	22	0			30.9	h. m. s. s.
	1	46	14	37	50	40			29.4	$\Delta c=+0$ 57 28.6 ± 0.34
	1	46	53	37	45	50			27.8	
	1	47	50	37	31	0			26.9	
	1	48	18	37	23	0			29.2	
	1	49	37	37	2	10			28.5	
	1	51	49	36	43	30			26.4	
	1	53	8	36	5	20			29.0	
	1	53	43	35	55	40			29.7	
	1	55	56	34	23	30			26.8	
	1	56	44	34	0	40			32.3	
	1	57	6	33	55	20			29.7	
H. T.	2	7	52.7	30	54	30			31.0	
	2	8	30.3	30	44	40			28.0	
	2	10	28.1	31	17	0			24.3	
	2	11	20.0	31	0	10			30.9	
Dec. 14.9	7	35	38.0	27	26	30	+0	57	24.8	$dt=+0.1155\,dh+0.0811\,d\phi$
H. T.	7	36	20.5	27	39	40			27.0	h. m. s. s.
	7	36	54.2	27	48	30			23.3	$\Delta c=+0$ 57 28.0 ± 0.47
	7	37	54.5	28	7	40			28.4	
	7	41	20.0	30	13	30			32.0	
	7	42	7.2	30	27	20			32.6	
	7	43	25.1	30	47	50			25.9	
	7	44	35.5	31	10	0			32.4	
	7	45	44.1	31	28	30			28.6	
	7	46	15.2	31	37	20			28.4	
	7	46	42.0	31	45	20			29.7	
	7	47	19.8	31	56	10			29.9	
	7	48	20.5	31	7	40			27.2	
	7	49	2.5	31	18	50			24.6	
	7	49	40.2	31	30	0			26.4	
	7	50	28.3	31	43	40			26.9	

Sextant Observations—Continued.

Date.	Chronom. 1228.			Sextant R.			Corr. chronom. and latitude.			Results.
1870.	h.	m.	s.	°	′	″	°	′	″	MALTA.
Dec. 15.0	5	27	10	60	45	50	+35	54	1	h. m. s.
H. P.	5	27	51	60	47	10			14	Chr. 1228, 11 47 0
	5	28	44	60	48	40			23	Fr. 1915, 6 35 24.0
	5	40	21	61	4	0			27	° ′ ″ ″
	6	3	6	61	55	10			27	$\phi=+35\ 54\ 23\pm2.7$
	6	23	41	60	52	30			25	
	6	24	9	60	50	10			35	
	6	24	45	60	47	40			34	
							h.	m.	s.	
Dec. 15.1	1	35	30.5	40	43	40	+0	57	28.1	$dt=-0.1297\ dh\ -0.1002\ d\phi$
H. P.	1	36	1.5	40	35	0			31.3	h. m. s. s.
	1	36	34.5	40	27	10			29.6	$\Delta c=+0\ 57\ 29.2\pm0.34$
	1	37	7.0	40	20	0			25.3	
	1	38	30.0	38	52	40			30.5	
	1	38	53.0	38	47	0			29.4	
	1	39	15.5	38	42	10			26.2	
	1	39	50.5	38	32	30			28.9	
	1	40	32.5	38	21	20			30.7	
	1	41	23.0	38	7	50			32.6	
	1	41	58.0	37	59	20			30.6	
	1	42	58.0	37	43	50			30.6	
	1	43	44.5	38	36	40			29.8	
	1	44	25.0	38	26	30			28.3	
	1	45	40.0	38	6	30			30.1	
	1	46	10.5	37	59	30			26.0	
Dec. 15.9	7	45	48.2	31	16	50	+0	57	28.1	$dt=+0.1177\ dh\ +0.0841\ d\phi$
H. T.	7	46	47.1	31	34	20			30.4	h. m. s. s.
	7	47	20.2	31	43	10			28.4	$\Delta c=+0\ 57\ 28.7\pm0.18$
	7	47	43.2	31	49	50			28.8	
	7	48	28.0	30	58	0			30.3	
	7	49	0.0	31	7	0			30.1	
	7	49	25.6	31	13	50			28.6	
	7	49	48.5	31	20	30			29.3	
	7	50	36.7	31	33	40			27.7	
	7	51	8.2	31	42	50			28.9	
	7	51	35.8	31	50	50			29.7	
	7	52	6.3	31	59	0			28.3	
	7	53	20.3	33	24	10			26.5	
	7	53	44.5	33	31	10			27.5	
	7	54	15.5	33	40	0			28.3	
	7	54	40.5	33	46	50			27.7	

Sextant Observations—Continued.

Date.	Chronom. 1228.	Sextant R.	Corr. chronom. and latitude.	Results.
1870.	h. m. s.	° ′ ″	h. m. s.	MALTA.
Dec. 16.1	1 37 40.0	40 14 0	+0 57 28.1	
H. P.	1 38 17.0	40 4 20	29.3	$dt=-0.1289\,dh\ -0.0992\,d\varphi$
	1 38 43.5	39 57 10	31.2	h. m. s. s.
	1 39 14.5	39 49 20	30.8	$\Delta c=+0\ 57\ 29.7\pm0.18$
	1 40 36.0	38 23 40	30.3	
	1 41 8.0	38 16 0	28.3	
	1 41 41.0	38 7 0	30.3	
	1 42 12.0	37 59 0	30.5	
	1 43 16.0	37 43 0	28.5	
	1 43 39.0	37 36 30	30.5	
	1 44 0.5	37 31 30	29.9	
	1 44 24.0	37 25 0	29.8	
	1 45 38.5	38 10 50	29.0	
	1 46 11.5	38 2 0	29.9	
	1 46 36.0	37 56 10	27.5	
	1 47 2.0	37 48 30	30.8	
Dec. 16.9	7 31 14.0	25 6 10	+1 0 38.2	SYRACUSE.
H. H.	7 32 40.5	25 30 50	36.8	$dt=+0.1177\,dh\ +0.0830\,d\varphi$
	7 34 6.0	25 55 40	37.3	h. m. s. s.
	7 35 32.5	26 21 10	39.3	$\Delta c=+1\ 0\ 37.4\pm0.22$
	7 37 44.0	28 3 30	38.5	$\Delta t=+\quad 1.5$
	7 38 47.5	28 21 30	38.2	
	7 39 53.5	28 40 20	38.6	
	7 41 23.5	29 5 50	38.7	
	7 42 52.5	29 30 10	36.3	
	7 43 53.0	29 47 50	38.9	
	7 45 14.5	30 10 0	36.6	
	7 46 9.5	30 25 20	36.9	
	7 47 25.5	29 40 50	35.5	
	7 48 27.5	29 58 40	37.1	
	7 49 47.5	30 20 20	35.9	
	7 50 20.5	30 29 10	35.2	
			° ′ ″	° ′ ″ ″
Dec. 17.0	10 51 31	59 40 40	+37 3 54	$\varphi=+37\ 3\ 57\pm1.5$
H. H.	10 52 39	59 41 10	53	
	10 53 32	59 41 20	52	
	10 54 38	58 36 50	42	
	10 55 28	58 36 40	49	
	10 56 16	58 36 25	56	
	10 57 20	58 36 0	65	
	10 58 4	58 35 55	61	
	10 58 57	58 35 50	57	
	11 0 16	58 40 15	61	
	11 1 20	58 39 40	60	
	11 2 16	58 38 40	72	

Sextant Observations—Continued.

Date.	Chronom 1228.			Sextant R.			Corr. chronom. and latitude.			Results.
1870.	h.	m.	s.	°	'	"	h.	m.	s.	SYRACUSE.
Dec. 17.1	1	53	0.0	33	43	0	+1	0	41.4	$dt=-0.1220\,dh-0.0889\,d\phi$
H. E.	1	54	48.5	33	13	40			42.4	h. m. s. s.
	1	55	50.0	32	57	30			41.4	$\Delta c=+1$ 0 40.9 ± 0.19
	1	56	22.0	32	48	50			41.6	$\Delta t=-$ 1.6
	1	57	25.5	31	27	10			40.1	
	1	58	0.5	31	17	20			41.3	
	1	58	34.5	31	8	10			41.1	
	1	59	2.0	31	0	20			42.4	
	1	59	56.0	30	45	50			41.6	
	2	0	24.0	30	39	0			38.7	
	2	1	5.5	30	27	0			41.5	
	2	1	34.0	30	19	10			41.1	
	2	2	15.5	31	15	50			39.7	
	2	2	40.0	31	6	10			40.4	
	2	3	10.5	30	58	10			38.9	
	2	3	48.0	30	47	30			40.0	
Dec. 17.9	7	39	1.0	28	13	20	+1	0	36.4	$dt=+0.1230\,dh+0.0902\,d\phi$
H. H.	7	40	25.5	28	37	50			38.2	h. m. s. s.
	7	41	59.0	29	4	10			38.0	$\Delta c=+1$ 0 36.5 ± 0.30
	7	43	21.5	29	27	20			37.8	$\Delta t=+$ 1.6
	7	44	43.0	28	45	10			37.6	
	7	46	2.5	29	7	20			37.7	
	7	47	30.0	29	31	40			37.7	
	7	48	30.5	29	48	0			36.7	
	7	59	6.0	33	44	40			35.9	
	8	2	7.5	34	33	10			36.5	
	8	3	24.5	34	54	0			39.1	
	8	4	41.0	35	12	50			34.8	
	8	6	42.0	34	39	30			36.0	
	8	7	57.5	34	58	10			33.1	
	8	9	9.0	35	17	0			34.9	
	8	10	13.5	35	33	0			33.2	
Dec. 18.1	1	42	5.5	36	38	0	+1	0	42.0	$dt=-0.1290\,dh-0.0983\,d\phi$
H. E.	1	42	37.0	36	29	10			45.2	h. m. s. s.
	1	43	7.5	36	22	20			41.5	$\Delta c=+1$ 0 41.8 ± 0.22
	1	43	46.0	35	7	20			41.9	$\Delta t=-$ 1.8
	1	44	17.5	34	59	20			41.6	
	1	44	44.0	34	52	40			41.1	
	1	45	2.0	34	48	0			41.2	
	1	45	51.5	34	35	0			42.1	
	1	46	15.0	34	29	10			41.2	
	1	46	53.5	34	19	0			40.7	
	1	47	32.5	35	14	0			41.5	
	1	47	58.5	35	7	20			41.0	
	1	48	28.0	34	59	10			42.9	

Sextant Observations—Continued.

Date.	Chronom. 1228.	Sextant R.	Corr. chronom. and latitude.	Results.
1870.	h. m. s.	° ′ ″	h. m. s.	SYRACUSE.
Dec. 18.9	7 23 49.0	22 33 20	+ 1 0 38.2	
H. E.	7 27 0.0	23 29 40	38.8	$dt = +0.1145\, dh + 0.0783\, d\phi$
	7 28 14.0	23 51 10	37.8	h. m. s. s.
	7 29 22.5	24 11 0	37.0	$\Delta c = +1$ 0 37.3 ± 0.14
	7 32 47.0	26 15 20	36.5	$\Delta t = +$ 1.3
	7 33 17.0	26 24 10	37.0	
	7 33 46.5	26 33 0	37.8	
	7 34 14.5	26 41 10	38.3	
	7 34 52.0	26 51 20	35.8	
	7 35 16.5	26 58 40	37.0	
	7 35 40.0	27 5 20	36.4	
	7 36 9.0	27 13 20	37.8	
	7 36 57.0	26 22 40	36.8	
	7 37 21.5	26 29 50	37.4	
	7 37 44.5	26 36 20	37.2	
	7 38 7.5	26 42 40	36.5	° ′ ″ ″
Dec. 19.0	10 47 37	59 30 20	+37° 3′ 68″	$\phi = +37$ 3 61 ± 1.8
H. H.	10 48 38	59 31 50	51	
	10 49 52	59 32 40	57	
	10 51 13	59 34 0	50	
	10 52 28	58 29 30	72	
	10 53 41	58 29 50	52	
	10 54 37	58 30 0	51	
	10 55 33	58 30 30	42	
	10 57 3	58 30 0	59	
	10 58 2	58 29 50	64	
	10 59 3	58 29 40	54	
	11 0 2	58 29 0	70	
	11 1 40	59 33 50	57	
	11 2 42	59 32 30	78	
	11 3 44	59 31 50	75	
	11 5 0	59 30 45	75	
Dec. 19.1	1 48 21.0	34 1 55	+ 1 0 41.7	$dt = -0.1234\, dh - 0.0908\, d\phi$
H. H.	1 49 30.0	33 44 0	41.2	h. m. s. s.
	1 50 21.5	33 30 30	41.5	$\Delta c = +1$ 0 39.5 ± 0.25
	1 51 22.5	33 15 0	39.3	$\Delta t = -$ 1.7
	1 52 58.5	33 54 30	39.9	
	1 54 5.0	33 36 20	41.8	
	1 55 41.5	33 11 0	40.2	
	1 56 31.0	32 57 50	39.9	
	1 58 11.0	32 31 20	37.8	
	1 59 9.5	32 15 20	38.9	
	2 0 11.5	31 58 30	39.0	
	2 2 1.0	31 29 10	37.1	
	2 2 59.5	30 7 10	37.6	
	2 4 7.5	29 48 50	39.3	
	2 4 58.5	29 35 0	38.3	
	2 5 46.0	29 21 40	39.2	

Sextant Observations—Continued.

Date.	Chronom. 1228.	Sextant R.	Corr. chronom. and latitude.	Results.
1870.	h. m. s.	° ′ ″	° ′ ″	SYRACUSE.
Dec. 19.3	5 54 57.0	76 51 40	+37 3 17	
H. H.	5 56 53.0	76 53 40	73	° ′ ″ ″
	5 58 6.5	76 52 40	40	$\phi = +37\ 3\ 39 \pm 2.6$ *Polaris.*
	6 0 15.5	76 52 50	41	
	6 1 47.0	76 52 50	39	
	6 3 21.5	76 52 40	30	
	6 4 37.0	76 53 0	40	
	6 5 32.5	76 52 40	28	
	6 9 2.5	76 53 10	40	
	6 10 13.0	76 53 0	34	
	6 11 8.0	76 52 30	55	
	6 11 56.5	76 53 10	37	
Dec. 20.3	6 32 27.0	76 52 10	+37 3 19	° ′ ″ ″
H. H.	6 35 22.5	76 52 20	29	$\phi = +37\ 3\ 31 \pm 2.3$ *Polaris.*
	6 36 56.0	76 52 30	38	
	6 38 28.5	76 52 40	46	
	6 40 33.5	76 52 0	31	
	6 42 50.0	76 51 50	32	
	6 44 16.0	76 51 55	38	
	6 45 31.0	76 51 10	18	
			h. m. s.	
Dec. 20.9	7 23 37.5	23 13 30	+1 0 37.5	$dt = +0.1145\, dh + 0.0783\, d\phi$
H. H.	7 24 53.0	23 36 0	39.0	h. m. s. s.
	7 26 9.5	24 1 40	37.6	$\Delta c = +1\ 0\ 38.1 \pm 0.26$
	7 27 21.0	24 19 50	37.6	$\Delta t = +\ 1.3$
	7 29 43.5	23 56 50	37.2	
	7 30 54.5	24 17 30	36.7	
	7 32 36.5	24 47 0	35.9	
	7 33 46.0	25 7 30	37.0	
	7 35 38.0	25 40 10	38.0	
	7 36 49.0	26 0 20	37.0	
	7 37 59.0	26 20 50	38.4	
	7 39 11.0	26 41 50	39.8	
	7 41 2.0	28 18 20	39.8	
	7 42 10.0	28 36 50	37.2	
	7 43 1.5	28 52 20	40.6	
	7 44 30.0	29 17 20	40.8	
			° ′ ″	° ′ ″ ″
Dec. 21.0	10 45 14.0	59 22 50	+37 3 79	$\phi = +37\ 3\ 61 \pm 1.4$
H. H.	10 46 47.0	59 25 0	74	
	10 47 12.5	59 25 40	67	
	10 47 39.5	59 26 0	73	
	10 48 6.0	58 21 50	59	
	10 48 35.5	58 22 30	53	
	10 49 27.0	58 23 10	58	
	10 50 53.0	58 24 20	58	
	10 51 50.0	58 25 10	54	
	10 52 44.0	58 25 20	64	

Sextant Observations—Continued.

Date.	Chronom. 1228.	Sextant R.	Corr. chronom. and latitude.	Results.
1870.	h. m. s.	° ′ ″	° ′ ″	SYRACUSE.
Dec. 21.0	10 53 35.0	58 26 10	+37 3 51	
H. H.	10 54 35.0	58 26 20	59	
	11 1 9.0	59 31 10	63	
	11 3 10.0	59 30 10	63	
	11 3 42.0	59 30 10	53	
	11 4 29.0	59 29 30	56	
			h. m. s.	
Dec. 21.1	1 57 9.8	31 56 20	+1 0 39.0	$dt = -0.1222\, dh - 0.0892\, d\phi$
H. T.	1 57 31.1	31 50 40	38.9	h. m. s. s.
	1 57 51.0	31 45 30	38.2	$\Delta c = +$ 1 0 39.1 ± 0.11
	1 58 45.1	31 31 0	38.0	$\Delta t = -$ 1.6
	1 59 28.1	32 24 0	39.4	
	1 59 50.6	32 17 50	39.7	
	2 0 22.0	32 9 30	39.0	
	2 0 42.5	32 4 10	38.2	
	2 1 36.1	31 49 30	38.5	
	2 2 4.7	31 41 20	39.9	
	2 2 43.0	31 31 10	39.2	
	2 3 12.6	31 22 40	40.4	
	2 3 42.0	30 10 0	39.1	
	2 4 10.4	30 2 0	39.9	
	2 4 31.5	29 56 30	38.7	
	2 4 57.5	29 49 10	39.4	
			h. m. s.	
Dec. 21.9	7 30 43.0	24 5 30	+1 0 37.7	$dt = +0.1145\, dh + 0.0782\, d\phi$
H. T.	7 31 15.7	24 14 50	36.9	h. m. s. s.
	7 31 37.8	24 21 30	37.4	$\Delta c = +$ 1 0 35.9 ± 0.25
	7 31 57.5	24 27 30	38.3	$\Delta t = +$ 1.3
	7 32 55.2	25 48 40	36.8	
	7 33 20.7	25 55 50	35.9	
	7 33 49.5	26 4 30	36.8	
	7 34 11.5	26 10 50	36.7	
	7 34 57.5	26 23 20	33.8	
	7 35 20.2	26 30 10	34.7	
	7 35 44.9	26 37 20	34.8	
	7 36 10.6	26 44 50	35.1	
	7 36 42.7	25 50 20	39.0	
	7 37 6.9	25 56 10	35.1	
	7 37 28.7	26 2 10	34.1	
	7 37 54.8	26 10 0	35.2	
	7 38 23.0	26 18 0	35.0	

The following are the observations for index correction, to which are added the observed values of the sun's diameter compared with the computed values :

Date.	Sextant readings.		Index correction.	Sun's diameter. Observed.	Sun's diameter. Computed.	Difference.	
	° ′ ″	° ′ ″	′ ″	′ ″	′ ″	″	
Dec. 12.9	0 31 17.5	359 25 50.0	+ 1 26	32 44	32 31	+ 13	Low power.
13.0	31 25.0	359 25 41.7	+ 1 27	32 52	32 33	+ 19	Low power.
13.9	31 6.0	359 25 40.0	+ 1 37	32 43	32 28	+ 15	Low power.
14.0	31 21.7	359 25 46.7	+ 1 26	32 47	32 32	+ 15	Low power.
14.1	31 40.6	359 25 21.7	+ 1 29	33 9	32 30	+ 39	Low power.
14.9	31 23.3	359 25 31.7	+ 1 32	32 56	32 29	+ 27	Low power.
15.0	31 17.2	359 26 12.2	+ 1 15	32 32	32 32	0	
15.1	31 16.7	359 26 16.7	+ 1 13	32 30	32 31	— 1	
15.9	31 15.0	359 26 0.0	+ 1 22	32 37	32 29	+ 8	
16.1	31 15.0	359 26 20.0	+ 1 12	32 28	32 31	— 3	
16.9	31 5.0	359 26 15.0	+ 1 20	32 25	32 27	— 2	
17.0	31 12.5	359 26 8.3	+ 1 20	32 32	32 33	— 1	
17.1	31 6.3	359 26 6.3	+ 1 24	32 30	32 27	+ 3	
17.9	31 16.7	359 26 10.0	+ 1 17	32 33	32 29	+ 4	
18.1	31 3.3	359 26 16.7	+ 1 20	32 26	32 31	— 5	
18.9	31 12.5	359 26 13.3	+ 1 17	32 30	32 26	+ 4	
19.0	31 15.8	359 26 19.2	+ 1 13	32 28	32 33	— 5	
19.1	31 13.3	359 26 16.7	+ 1 15	32 28	32 29	— 1	
19.3	. . .	359 58 31.7	+ 1 28	Polaris.			
20.3	. . .	359 58 36.7	+ 1 23	Polaris.			
20.9	31 5.8	359 26 10.0	+ 1 22	32 28	32 25	+ 3	
21.0	31 17.5	359 26 9.1	+ 1 17	32 34	32 33	+ 1	
21.1	31 15.0	359 26 16.7	+ 1 14	32 29	32 29	0	
21.9	31 8.3	359 26 11.7	+ 1 20	32 28	32 25	+ 3	

If we consider the spherical triangle formed by the star, the zenith of the observer, and the pole of the heavens, and designate by h, δ, t, the altitude, the declination, and hour angle of the star, we shall have the equation,

$$\sin h = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos t$$

Since sextant observations for time should be made as near the prime-vertical as practicable, the hour angle will be accurately determined by means of its cosine, and the above simple formula is, I think, more convenient for computation, and more exact than the transformed expressions that are usually employed. For the reduction of the latitude observations I have used the following formula derived from the preceding one by an easy transformation:

$$\cos (\varphi - \delta) = \sin h + 2 \cos \varphi \cos \delta \sin \tfrac{1}{2} t^2$$

If we differentiate the first equation, considering δ constant and denoting by A the azimuth, we shall have,

$$dt = - \frac{dh}{\cos \varphi \sin A} - \frac{d\varphi}{\cos \varphi \tan A}$$

This differential equation shows the importance of making the observations for time symmetrical with respect to the meridian. It has been computed for the mean hour angle in each set of observations, dt being expressed in seconds of time, and dh and $d\varphi$ in seconds of arc.

At Malta my observing station was at the telegraph office except on the first day, December 13, when the observations were made at Spencer's Monument. According to the map of the Ordnance Survey of Malta, Spencer's Monument is 253 yards west and 2,013 yards south of the telegraph office. In reducing the observations made at Syracuse the latitude was assumed to be $+37° 3'.5$, and a reduction, Δt, to the latitude finally adopted, is given in the column of results.

The following are the values of the latitudes obtained from the sextant observations:

		°	′	″	
Malta, Spencer's monument,	$\varphi = +$	35	52	55;	16 altitudes of the sun.
Malta, telegraph office,	$\varphi = +$	35	54	11;	20 altitudes of the sun.
Syracuse, Bastione San Filippo,	$\varphi = +$	37	3	57;	12 altitudes of the sun.
Syracuse, Bastione San Filippo,			3	61;	16 altitudes of the sun.
Syracuse, Bastione San Filippo,			3	61;	16 altitudes of the sun.
Syracuse, Bastione San Filippo,			3	39;	12 altitudes of Polaris.
Syracuse, Bastione San Filippo,			3	31;	8 altitudes of Polaris.
Mean latitude,	$\varphi = +$	37	3	48	

Corrections of Chronometer Negus 1228 *on Local Mean Time.*

Place.	Date.	A. M.				P. M.				Mean.			
	1870.		h.	m.	s.		h.	m.	s.		h.	m.	s.
Malta . .	Dec. 13	+	0	57	29.6								
	14	+	0	57	28.4	+	0	57	28.6	+	0	57	28.5
	15	+	0	57	28.0	+	0	57	29.2	+	0	57	28.6
	16	+	0	57	28.7	+	0	57	29.7	+	0	57	29.2
Syracuse .	Dec. 17	+	1	0	38.9	+	1	0	39.3	+	1	0	39.1
	18	+	1	0	38.1	+	1	0	40.0	+	1	0	39.0
	19	+	1	0	38.6	+	1	0	37.8	+	1	0	38.2
	21	+	1	0	39.4	+	1	0	37.5	+	1	0	38.4
	22	+	1	0	37.2								

When at Malta I was permitted by M. Berthet to use his transit-instrument. This instrument, made by Secretan, of Paris, in 1862, has an objective of three inches, and is very well mounted in an observatory on St. James Cavalier, the meridian of which differs but little from that of the telegraph office. As the value of the level divisions had not been determined, the level, and also the collimation error, were made zero by M. Berthet a short time before the observations. The wires of the instrument were too thick to admit of very accurate observations of transits, but the following may serve as a check on the determinations of time with the sextant:

Date.	Star.	Wires.	Chron. 1228.			App. α.			Corr. chron.			
1870.			h.	m.	s.	h.	m.	s.	h.	m.	s.	
December 14	γ Ceti	5	8	5	59.44	2	36	36.84	+ 0	57	28.48	
	α Ceti	5	8	24	51.74	2	55	32.10		57	28.33	
	δ Arietis . .	5	8	33	33.38	3	4	15.16		57	28.32	
	α Persei . . .	5	8	44	23.74	3	15	7.54		57	28.55	
December 15	12 Ceti	5	5	49	14.76	0	23	26.40	+ 0	57	29.59	
	β Ceti	5	6	2	52.30	0	37	5.82		57	29.46	
	γ Cassiopeæ .	5	6	14	38.66	0	48	56.20		57	29.69	
	ϵ Piscium . .	5	6	21	56.88	0	56	14.30		57	28.74	
	Polaris . .	3	6	37	2.	1	11	58.		57	29.	
	ν Piscium . .	5	7	0	19.40	1	34	42.59		57	29.31	
	β Arietis . .	5	7	13	5.20	1	47	30.51		57	29.09	

TELEGRAPHIC SIGNALS FOR LONGITUDE.

Through the kindness of Mr. Rosenbusch the telegraph offices at Malta and Syracuse were furnished with small portable and very convenient instruments for sending and receiving the signals. Each instrument was provided with two keys, worked by the observers, and the signals were given by the observer striking his key in coincidence with the beat of his chronometer. The signals were recorded on a fillet of paper similar to that used with the Morse register. For example, the observer at Syracuse gave signals every fifth second of his chronometer for three minutes, the observer at Malta during the same time giving signals at every second of his chronometer, and, both sets of signals being recorded on the fillet of the Malta instrument, a very accurate comparison of the chronometers was obtained. The operation was then reversed, the observer at Malta sending signals every fifth second to Syracuse, and the chronometers were compared on the fillet of the Syracuse instrument. The following are the results of the readings of the fillets. At Syracuse the signals were made by Professor Harkness, who used the chronometer Negus 1115. At Malta I used the chronometer Negus 1228.

Date.	Malta fillet. Ch. 1228—Ch. 1115	Syracuse fillet. Ch. 1228—Ch. 1115
1870. h.	m. s.	m. s.
Dec. 13, 0.4	+ 2 4.22	+ 2 4.23
14, 3.3	+ 2 4.44	+ 2 4.47
15, 3.5	+ 2 4.79	+ 2 4.80
16, 1.1	+ 2 5.25	+ 2 5.23

If we denote by c and c' the chronometer times when the signal was sent and received, and by Δc and $\Delta c'$ the corrections of the chronometers, the difference of longitude will be,

$$c - c' + \Delta c - \Delta c' + \varepsilon$$

where ε is the time required for the signal to pass from one station to the other. The present observations do not furnish data for the determination of ε, and its further consideration is omitted. The preceding table gives the values of $c-c'$, and Professor Harkness has furnished the corrections of the chronometer Negus 1115. Collecting the necessary quantities, we have the following results for the difference of longitude between the telegraph office in Malta and our station in Syracuse:

Date.	Corr. ch. 1228.	Corr. ch. 1115.	$c-c'$	$\Delta\lambda$
1870.	h. m. s.	h. m. s.	m. s.	m. s.
December 13	+ 0 57 28.3	+ 1 2 43.2	+ 2 4.2	− 3 10.7
14	+ 0 57 28.5	+ 1 2 44.0	+ 2 4.4	− 3 11.1
15	+ 0 57 28.7	+ 1 2 44.4	+ 2 4.8	− 3 10.9
16	+ 0 57 29.2	+ 1 2 44.7	+ 2 5.2	− 3 10.3

Taking the mean of these results, we have Syracuse east of Malta

$$3^{m}\ 10^{s}.7 \pm 0^{s}.33$$

Omitting all consideration of personal equation in sending the signals, the comparison of the chronometers by means of the telegraph may be considered as exact, since from 164 comparisons it results that the probable error of a single comparison is only $\pm 0^{s}.034$. From the 240 altitudes observed, I find that the prob-

able error of one of my time determinations from the mean of 12 altitudes is $\pm 0^s.27$. On the other hand, the sun was observed at azimuths of about forty degrees only east and west of the meridian, and the differential equations show that an error of 10″ in the altitude will produce an error of more than one second in the time. From these considerations I estimate the probable error in the difference of longitude to be one-third of a second.

The following is the record of the signals exchanged with Professor Newcomb, who was at Gibraltar. In sending the signals, the observer struck the telegraph key in coincidence with the beat of his chronometer. The signals were received in the following manner: A telegraph-operator watched the bright image of the mirror, and at the instant he observed a motion of the image he struck a key that gave a sharp click, and the time of this click was observed on the chronometer at Gibraltar by Professor Newcomb, and at Malta by myself.

Record of Signals.

MALTA RECORD.				GIBRALTAR RECORD.			
Date.	Chron. 1228.	Chron. 1265.	Difference.	Date.	Chron. 1265.	Chron. 1228.	Difference.
1870.	h. m. s.	h. m. s.	m. s.	1870.	h. m. s.	h. m. s.	m. s.
Dec. 15	4 45 0.6:	4 45 15.0	0 14.4:	Dec. 15	4 52 17.7?	4 52 0	0 17.7?
	45 15.6:	45 30.0	14.4:		52 32.0?	52 15	17.0?
	45 29.5	45 45.0	15.5		52 47.1	52 30	17.1
	45 43.5	46 0.0	16.5		53 2.4	52 45	17.4
	45 58.5	46 15.0	16.5		53 17.4	53 0	17.4
	46 13.5	46 30.0	16.5		53 32.4	53 15	17.4
	46 28.6	46 45.0	16.4		53 47.3	53 30	17.3
	46 43.5	47 0.0	16.5		54 2.5	53 45	17.5
	46 58.6	47 15.0	16.4		54 17.3	54 0	17.3
	47 14.5	47 30.0	15.5		54 32.3	54 15	17.3
	47 28.7	47 45.0	16.3		54 47.3	54 30	17.3
	47 43.5	48 0.0	16.5		55 2.2	54 45	17.2
	47 58.6	48 15.0	16.4		55 17.3	55 0	17.3
	48 13.5	48 30.0	16.5		55 32.4	55 15	17.4
	48 28.6	48 45.0	16.4		55 (47.3)?	55 30	17.3?
	48 43.5	49 0.0	16.5		56 2.5	55 45	17.5
	48 58.5	49 15.0	16.5		56 17.3	56 0	17.3
	49 13.6	49 30.0	16.4		56 32.2	56 15	17.2
	49 29.0	49 45.0	16.0		56 47.4	56 30	17.4
	49 43.5	50 0.0	16.5		57 2.4	56 45	17.4
					57 17.4	57 0	17.4

Mean, (18,) $0^m\ 16^s.32 \pm 0^s.016$ Mean, (18,) $0^m\ 17^s.34 \pm 0^s.006$

Record of Signals—Continued.

MALTA RECORD.				GIBRALTAR RECORD.			
Date.	Chron. 1228.	Chron. 1265.	Difference.	Date.	Chron. 1265.	Chron. 1228.	Difference.
1870.	h. m. s.	h. m. s.	m. s.	1870.	h. m. s.	h. m. s.	m. s.
Dec. 16	11 31 43.2	23 32 0.0	0 16.8	Dec. 16	23 39 (18.7):	11 39 0	0 18.7:
	31 58.0	32 15.0	17.0		39 32.7:	39 15	17.7:
	32 13.0	32 30.0	17.0		39 48.0:	39 30	18.0:
	32 28.0	32 45.0	17.0		40 3.0	39 45	18.0
	32 43.0	33 0.0	17.0		40 17.9:	40 0	17.9:
	32 58.0	33 15.0	17.0		40 33.0	40 15	18.0
	33 13.0	33 30.0	17.0		40 48.1	40 30	18.1
	33 28.1	33 45.0	16.9		41 3.2	40 45	18.2
	33 43.0	34 0.0	17.0		41 18.2	41 0	18.2
	33 57.9	34 15.0	17.1		41 33.2	41 15	18.2
	34 13.0	34 30.0	17.0		41 48.1	41 30	18.1
	34 28.0	34 45.0	17.0		42 3.2	41 45	18.2
	34 43.0	35 0.0	17.0		42 18.0	42 0	18.0
	34 58.2	35 15.0	16.8		42 33.0	42 15	18.0
	35 13.0	35 30.0	17.0		42 48.1	42 30	18.1
	35 28.2	35 45.0	16.8		43 3.2	42 45	18.2
	35 43.1	36 0.0	16.9		43 18.3	43 0	18.3
	35 58.0	36 15.0	17.0		43 33.2	43 15	18.2
	36 13.0	36 30.0	17.0		43 48.1	43 30	18.1
	36 28.2	36 45.0	16.8		44 3.0	43 45	18.0
	36 43.1	37 0.0	16.9		44 18.3	44 0	18.3

Mean, (21,) $0^m\ 16^s.95 \pm 0^s.004$ Mean, (17,) $0^m\ 18^s.13 \pm 0^s.005$

Hence collecting the quantities and using the corrections of chronometer 1265 found by Professor Newcomb, we have the following results:

Date.	Corr. chron. 1228.	Corr. chron. 1265.	$c - c'$	$\Delta\lambda$
1870.	h. m. s.	h. m. s.	m. s.	h. m. s.
Dec. 15	+ 0 57 28.7	− 0 22 16.5	− 0 16.8	1 19 28.4
16	+ 0 57 29.2	− 0 22 15.3	− 0 17.5	1 19 27.0

The determination of time at Gibraltar, on December 16, is from an observation of α Lyræ, while the determination of the 15th is from four observations east and west of the meridian, and is therefore much more trustworthy. I adopt, as the difference of longitude,

$$1^h\ 19^m\ 28^s.4 \pm 0^s.5$$

If we reject the time determination of December 16 at Gibraltar, and assume a constant rate of the chronometer from the 15th to the 19th, the resulting longitude for the 16th will be $1^h\ 19^m\ 28^s.5$; but this process does not, I think, add any weight to the adopted value.

As indicated by the date, the principal part of the preceding report was written immediately after my return home and before I had seen any reports or discussions of the observations in Sicily. A small part of the numerical reductions could not be completed until I had received from Professors Newcomb and Harkness their determinations of local time.

Very respectfully, your obedient servant,

ASAPH HALL,
Professor of Mathematics, U. S. N.

Commodore B. F. SANDS, U. S. N.,
Superintendent U. S. Naval Observatory, Washington, D. C.

REPORT

OF

PROFESSOR WM. HARKNESS, U. S. N.

REPORT OF PROFESSOR WM. HARKNESS, U. S. N.

United States Naval Observatory,
Washington, July 13, 1871.

Sir: In accordance with orders from the Navy Department, dated September 16, 1870, I have the honor to submit to you the following report in relation to the astronomical and other observations made by me in connection with the expedition sent to Sicily, by this Observatory, for the purpose of observing the total solar eclipse of the 22d of December last.

I.—INTRODUCTORY.

I left Washington at 9 p. m., October 28, arriving in New York early the following morning. The next three days were spent in arranging details regarding the transportation of the officers and instruments of the party, and at 2 p. m., November 2, Professors Hall, Eastman, and I, sailed from Jersey City in the Cunard steamer China. After an unusually rough and disagreeable passage we arrived safely in Liverpool at 12.30 p. m., November 13. We had with us no less than ten cases of instruments, all of which were most courteously passed through the custom-house without being opened, and without a moment's delay, the authorities saying that they had received orders from the government at London to do so. At 4.45 p. m., November 15, Mr. Alvan Clark, jr., and I, left Liverpool by rail for York, where we spent the night. The next morning we visited the works of Messrs. T. Cooke & Sons, and in the afternoon, by appointment, we met Professor Newcomb at the railway station, and went on with him to Newcastle, and thence to Gateshead, for the purpose of seeing Mr. Newall's gigantic refracting telescope.

While on the train, Professor Newcomb told me that he had selected Gibraltar as the most suitable station from which to make his observations on the eclipse, and that he had made all necessary arrangements with the Astronomer Royal, and with the various telegraph companies whose wires would be required, to exchange longitude signals between Greenwich and that place. He also added that he had informed the managing directors of the submarine cables that it was probable I would be desirous of determining the difference of longitude between Gibraltar and my station at Syracuse, and that they had expressed their entire willingness to grant me the free use of their wires for that purpose if I would make known my wishes to them. Accordingly, when I subsequently passed through London, on my way to Southampton, I called on W. T. Ansell, esq., secretary of the Falmouth, Gibraltar, and Malta Telegraph Company, and he introduced me to Sir James Anderson, managing director of that company, and also of the Anglo-Mediterranean Telegraph Company. These gentlemen treated me with the greatest kindness, evincing a deep interest in our scientific operations, and showing a very strong desire to do all in their power to insure our success. They at once granted me the free use of their cables for the exchange of longitude signals, and furnished me with a letter of introduction to Benjamin Smith, esq., their superintendent at Malta, requesting him to afford me every possible facility. In addition, Sir James Anderson wrote a note to Edward Tombs, esq., secretary of the Mediterranean Extension Telegraph Company, who own the submarine cable between Malta and Sicily, requesting him to grant me the free use of their line, and to furnish me with a letter of introduction to Edward Rosenbusch, esq., their engineer and general superintendent at Malta. This was at once done, and I here desire to offer my thanks to all the above-named gentlemen for their liberality in the cause of science.

At 3 p. m., November 26, our party sailed from Southampton on the Peninsular and Oriental Company's steamer Poonah. During the voyage we touched at Lisbon and Gibraltar, and, after a tolerably pleasant passage, we landed at Malta about 12.30 a. m., December 6. A day or two before arriving at the last mentioned place I became slightly acquainted with one of my fellow passengers, who manifested some interest in our expedition, and who, upon learning that we contemplated using the telegraph cables for longitude purposes, said that he was a director in the company, and that when we got to Malta he would go

on shore and request their superintendent to afford me all possible assistance. He fulfilled his promise at the expense of no little personal inconvenience, for the Poonah reached Malta about half an hour after midnight and departed about daylight the following morning. While on board ship I was ignorant of the gentleman's name, but the superintendent at Malta subsequently told me that it was Mr. Elliot, of the well-known firm of Glass, Elliot & Co., and I here desire to offer him my thanks for his kind interest in the welfare of our expedition.

For the better understanding of what follows, it may be well to give some details as to the ownership and management of the telegraph lines which we proposed to use in determining differences of longitude. The land lines from the Greenwich Observatory to Porthcurno are owned and controlled by the English government, R. S. Culley, esq., being the engineer-in-chief. The submarine cables from Porthcurno to Lisbon, from Lisbon to Gibraltar, and from Gibraltar to Malta, are owned and controlled by the Falmouth, Gibraltar, and Malta Telegraph Company, Sir James Anderson, managing director, Benjamin Smith, esq., superintendent at Malta. The submarine cable from Malta to Modica, in Sicily, is owned and controlled by the Mediterranean Extension Telegraph Company, Edward Tombs, esq., secretary, Edward Rosenbusch, esq., engineer and general superintendent, residing at Malta. The land lines from Modica to Florence are owned by the Italian government, but one of the wires is leased to and controlled and worked by the Anglo-Mediterranean Telegraph Company, Sir James Anderson, managing director, Edward Rosenbusch, esq., engineer and general superintendent. Syracuse is on the line from Modica to Florence. It will thus be seen that in working from Malta to Syracuse we would be using the wires of two different companies, but, as Mr. Rosenbusch is engineer and general superintendent of both, the whole line is under the control of one man.

On the morning of December 6 I made inquiries as to where the offices of the various telegraph companies were to be found in Malta, and was told that they were all in the same building. I also learned that Mr. Smith, local superintendent of the Falmouth, Gibraltar, and Malta line, boarded at Dunsford's Hotel, where I was then staying. Accordingly, I called on him in his room, and presented my letter of introduction. He received me very kindly, and took me to the telegraph office, where, after showing me everything, he placed a clerk and a complete set of the company's apparatus at my disposal, in order that I might become quite familiar with it, as it was very different from the apparatus employed in the American telegraph offices. He assured me that there would not be the least difficulty in exchanging signals between Malta and Gibraltar, and that the only thing necessary was for me to designate what apparatus I wished used and how I would have it handled during the longitude work. This I did, and I have to thank him, and the gentlemen attached to his staff, for their very efficient assistance in carrying out our operations.

I next called on Mr. Rosenbusch, engineer and general superintendent of the Mediterranean Extension Telegraph Company, and of the Anglo-Mediterranean Telegraph Company—a gentleman whom I subsequently learned to know as one of the kindest and best friends that it was my good fortune to meet during my absence abroad. He told me that, so far as the Malta end of the line was concerned, there would not be any difficulty, for he was ready to do anything that I might deem necessary; but that at Syracuse the case was different, because the wire controlled by his company is a through one, and their contract with the Italian government only permits them to have offices at Modica and Florence. Hence, as all telegraph offices in Italy are controlled by the government, it would be necessary to secure its assent before it would be possible for us to use the company's wire between Modica and Syracuse. In order to procure this assent, Mr. Rosenbusch at once telegraphed to Florence to Commendatore Ernest d'Amico, director general of the Royal Italian telegraph lines, and in twenty-four hours I had the satisfaction of learning that Signor Emmanuele Astor, sub-inspector of the Royal Italian telegraphs, had been ordered to proceed to the telegraph office at Syracuse, and there to give us every possible facility for exchanging longitude signals with Malta. Moreover, as Signor Astor and the other telegraph officials whom I would meet at Syracuse spoke only Italian, a language of which I know very little, Mr. Rosenbusch kindly volunteered to accompany me to overcome all difficulties that might arise on that score, and to give me the benefit of his influence with various government officers at Syracuse, all of whom were his personal friends.

I was now ready to proceed to Syracuse, but, as the steamer was not advertised to sail until Friday evening, I amused myself during the interval of waiting by visiting the various objects of interest in and around Malta. And here I must not omit to mention that my pleasure in so doing was greatly enhanced by numerous kind attentions shown me by our consul, Lyell T. Adams, esq., and our vice-consul, William John Stevens, esq.

The Malta channel is often very rough, and at such times the small steamers of the Florio line, which carry the mails between Malta and Sicily, do not venture to cross. Unfortunately for us, Wednesday, Thursday, and Friday were quite stormy, and when we went to bed on Saturday night the steamer had not yet arrived.* At 6 o'clock on Sunday morning, December 11, I was awakened by the joyful tidings that the mail-steamer had just come in, and that she would depart for Syracuse as soon as her freight could be got on shore. I dressed rapidly, but there was much delay in getting breakfast, and I was afraid the steamer would be off without us. The fear was groundless. I, in company with Professor Eastman and Mr. Rosenbusch, was on board at 9 o'clock, and she did not sail till a quarter before 11. She was the Corriére Siciliano—a nice little boat—and after a very pleasant passage of about eight hours, she landed us in Syracuse at 7 o'clock in the evening. Professor Hall, in company with Dr. C. H. F. Peters, of the United States Coast Survey Eclipse Expedition, had gone over to Sicily on December 6, and had secured on our behalf the kind offices of our consular agent, N. Stella, esq., and of the English consul, Nicolo Bisani, esq. These gentlemen met us at the custom-house, and, thanks to them and to Mr. Rosenbusch, our personal baggage was passed without being opened, and we went at once to the Albergo della Vittoria, where we were furnished with pleasant quarters, and made very comfortable during our stay in Syracuse.

About 8 o'clock the same evening Mr. Rosenbusch and I visited the telegraph office in Syracuse, where we met Signor Emmanuele Astor, sub-inspector of Royal Italian telegraphs, Signor Raffaele Spagna, superintendent of the Syracuse office, and Signor Mario Lanza, assistant in the Syracuse office. We found these gentlemen willing to do everything in their power for us, and after a little consultation all the details relative to the exchange of longitude signals were satisfactorily arranged.

At 12.30 p. m., December 12, Professor Eastman, Mr. Rosenbusch, and I, made an official visit to Chevalier Achille Basile, royal prefect of the province of Syracuse, who received us most kindly, and said that it would afford him the greatest pleasure to be of service to us while we remained in Syracuse. That same afternoon he had the boxes containing our instruments passed through the custom-house without being opened, and delivered to us at our hotel.

II.—SITE OF OBSERVING-STATION.

After making a thorough reconnaissance of the whole city of Syracuse, the place which seemed to me best adapted for our observing-station was the bastion situated on the north side of the Prima Porta Terra. The surface of the ground there was 52 feet above the sea-level, and, with the exception of an arc of 55°, included between the true bearings S. 5° W. and S. 50° E., the horizon was perfectly unobstructed. The obstructions in the arc in question consisted of the buildings in the more elevated part of the city, but they nowhere rose so high as to interfere with astronomical observations.

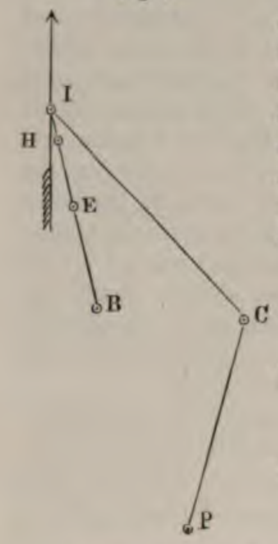
I accordingly wrote a note to the Prefect, requesting to be permitted to occupy the bastion as our observing-station, and asking for the loan of two tents to shelter our instruments. He replied that the bastion was at our service, and, if we wished, he would also give us the use of a large empty store-house in it. As our instruments were all so portable that it was not necessary to leave them in position during the night, the store-house was much better adapted to our wants than tents would have been, and I gladly accepted it. At 9 a. m., December 13, the Prefect sent an officer of his staff to take us to the bastion, to put us in possession of the store-house, and to inform us that he would have a military guard detailed, whose duty it would be to see that no injury came to our property. That same morning we had our boxes sent from the hotel to the store-house, got our instruments unpacked, and began observing. During the forenoon the guard arrived, and from that time till we left Syracuse there was always a sentinel at the door of the store-house.

On the evening of December 16, Messrs. A. Brothers and Alfred Fryer, of the English Eclipse Expedition, arrived in Syracuse; and on the morning of December 21, Mr. George Griffith, also of the English expedition, arrived. By our invitation, and with the consent of the Prefect, these gentlemen occupied the bastion and store-house in common with us as an observing-station.

* There are often very great delays, occasioned by rough weather, in getting from Malta to Sicily, and as there was every appearance that we were to be the victims of one of them, at a time when it was very important that we should get speedily to Syracuse, in order to determine our longitude, on Friday Vice-Admiral Sir Hastings Reginald Yelverton, K. C. B., commander-in-chief of H. B. M. Mediterranean squadron, sent a message to us through our consul, saying that if the mail-steamer did not arrive by Monday, he would on that day send us to Syracuse in his own dispatch-vessel, the Psyche. Such generosity should not be passed over in silence, and it gives me pleasure to offer the thanks of the party to Vice-Admiral Yelverton.

Figure 1, drawn on a scale of 1 to 2500, shows the exact positions occupied by the instruments of the different observers in the bastion. The point P is directly over the key-stone in the east, or city, face of the arch over the Prima Porta Terra. 1 is a stone gun-platform, which was situated near the northern end of the western face of the bastion. On it were made the observations for time and latitude, and on the day of the eclipse Professor Hall's telescope stood upon it. H and E indicate, respectively, the position of my telescope and of that of Professor Eastman. B is the position of Mr. Brothers's photographic telescope. Mr. Griffith's telescope stood between E and B. The following are the measured distances, corrected for error in length of tape-line:

Fig. 1.



1 to C = 316.2 feet = 96.38 meters.	1 to H = 34 feet = 10.4 meters.
C to P = 236.4 feet = 72.05 meters.	1 to E = 110 feet = 33.5 meters.
	1 to B = 226 feet = 68.9 meters.

The angles at 1 were

B and Belvedere Tower = 125° C and Belvedere Tower = 154° 35′

Angle 1 C P = 121° 30′

Hence I find

Distance from 1 to P = 483.8 feet = 147.5 meters.

Angle C 1 P = 24° 37′ 35″ Angle C P 1 = 33° 52′ 25″

The true bearing from 1 to the Belvedere Tower was N. 68° 23′ 28″ W. Combining this with the angles given above, I find for the true bearing from 1 to P, S. 18° 20′ 53″ E.

The instruments were used in the open air, and were carried back into the store-house whenever the observers were done with them for the time being. No shelter whatever was built for them.

III.—DESCRIPTION OF INSTRUMENTS.

With the exception of the chronometers, the instruments employed were all my own private property. As they were mostly the same ones that I used at Des Moines, in observing the eclipse of August 7, 1869, all of which are fully described in my report on that eclipse, Appendix II to the Washington Observations for 1867, pp. 26–32, it will only be necessary to give a list of them here, and to mention such changes as were made in them for the present eclipse.

An Achromatic Telescope of 43.58 inches focal length, and 3.01 inches clear aperture, made by Alvan Clark & Sons, of Cambridgeport, Massachusetts. This instrument is provided with a large battery of eye-pieces, ranging in power from 27.2 to 400 diameters. It is equatorially mounted on a very firm, portable tripod stand, which can be adjusted to any latitude, except very low ones, and has a slow motion by which it may be moved through a few degrees in azimuth. The polar and declination axes are both provided with clamp screws; but there are neither divided circles nor tangent screws.

The finder which was originally furnished with this telescope, and which was used at Des Moines, had a clear aperture of only 0.68 of an inch. This seemed to me too small; so I discarded it, and substituted another having an achromatic object-glass of 8.87 inches focus and 1.20 inches clear aperture. It is provided with a direct eye-piece magnifying 10.0 diameters, and a diagonal one magnifying 6.3 diameters. Each of them has a field of view 3° 15′ in diameter. The pointing apparatus is the adjustable needle-point which was used at Des Moines.

A Single-Prism Spectroscope, having the following optical constants:

Small telescope:	
Focal distance of object-glass	6.55 inches.
Clear aperture of object-glass	0.86 inch.
Diameter of field of view	5° 33′
Magnifying power	5.71 diameters.
Collimating lens for slit:	
Focal distance	6.52 inches.
Clear aperture	0.82 inch.

Collimating lens for scale:

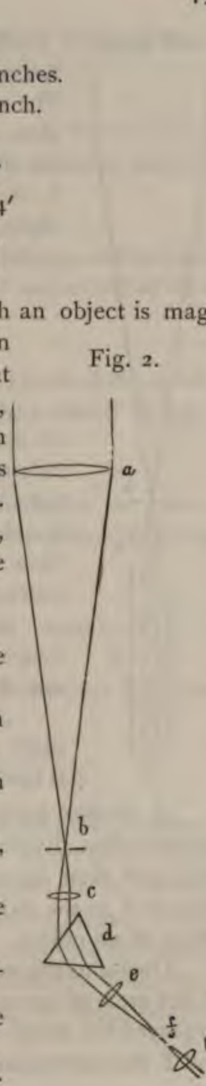
Focal distance	4.17 inches.
Clear aperture	0.82 inch.

Prism:

Refracting angle	60° 8′
Minimum deviation of line D	47° 44′
Refractive index	1.613
Density	3.532

It is often desirable to have a formula which will enable us to calculate how much an object is magnified when seen in the field of view of a spectroscope attached to a telscope. In order to obtain such a formula, let us consider a beam of perfectly homogeneous light—that is, light of but a single wave length—falling upon the object-glass of a telescope, *a*, Figure 2. It will be brought to a focus at *b*, and will there form an image between the jaws of the slit situated at that point. Then, passing through the collimating lens *c*, whose principal focus is at *b*, the rays composing the beam will be rendered parallel. Next, falling upon the prism *d*, the beam will be refracted and thrown upon the lens *e*, which will bring it to a focus at *f*, where a second image will be formed. This image will be viewed through the eye-lens *g*.

Fig. 2.



Now let

m = number of diameters which the image seen in the field of view of the spectroscope-telescope is magnified.

F = focal length of object-glass of main telescope—that is, of the lens *a* in Fig. 2.

c = focal length of the collimator of the spectroscope—that is, of the lens *c* in Fig. 2.

F' = focal length of the object-glass of the spectroscope-telescope—that is, of the lens *e* in Fig. 2.

f = focal length of the eye-piece of the spectroscope-telescope—that is, of the lens *g* in Fig. 2.

If the image formed at *f* were of exactly the same size as that formed at *b*, the magnifying power would evidently be equal to $\frac{F}{f}$; and the actual magnifying power will be greater or less than $\frac{F}{f}$, according as the image at *f* is larger or smaller than that at *b*. As the beam of light is supposed to contain rays of only a single wave length, the prism *d* can produce no effect upon it except that of bending it out of a straight path, and the size of the image at *b* must be to the size of the image at *f* as the focal length of the lens *c* is to the focal length of the lens *e*. The required formula will therefore be

$$m = \frac{F}{f} \times \frac{F'}{c}$$

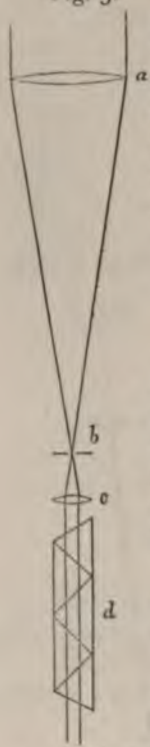
As it is desirable to avoid using the measured focal lengths of lenses whenever possible, this formula may be written

$$m = \frac{F}{c} \times \frac{F'}{f}$$

where $\frac{F'}{f}$ is the magnifying power of the spectroscope-telescope—a quantity which can be at once determined by means of a Ramsden's dynameter. Applying this formula to the case of the spectroscope, whose optical constants are given above, used in connection with the telescope of 43.58 inches focus, we find

$$m = \frac{43.58}{6.52} \times 5.71 = 38$$

Fig. 3.



If, instead of an ordinary spectroscope, one of Mr. Browning's small direct-vision instruments is employed, the formula given above will require to be somewhat modified. The optical arrangement will then be that shown in Fig. 3. The light falling on the object-glass *a* will be brought to a focus at *b*, and will there form an image between the jaws of the slit situated at that point. Then, passing through the lens *c*, whose principal focus is at *b*, the rays composing the beam will be rendered parallel, and after traversing the direct-vision prism *d* they will be viewed by the eye of the observer. Adopting the same notation as before, in this case we shall evidently have

$$m = \frac{F}{c}$$

An Arago Polariscope of double rotation, consisting of a brass tube 1.07 inches in diameter and 9.4 inches long, one end of which contains two plates of quartz, each cut perpendicularly to the axis, of the same thickness, and standing side by side, but one of them possessing right-handed rotation, the other left-handed rotation. The other end of the tube contains a double-image prism, and a convex lens of 9.0 inches focal length, which produces distinct vision of the compound plate of quartz to an eye placed at the double-image prism. This instrument gives images of complementary colors when polarized light is present.

An Arago Polariscope, consisting of a plate of selenite, and a double-image prism, giving images of complementary colors when polarized light is present. This instrument is fitted to one of the eye pieces of the 43-inch telescope.

A Savart Polariscope, consisting of a plate of quartz cut obliquely to the axis, and a plate of tourmaline, giving Savart's bands when polarized light is present. This instrument is also fitted to one of the eye pieces of the 43-inch telescope.

A Sextant, made by Stackpole & Brother, of New York, from my own designs, marked No. 937, of six inches radius, divided on platinum, and reading to ten seconds, having a telescope of 5.32 inches focus and 0.89 inch clear aperture, provided with eye-pieces magnifying respectively 2.75, 5.66, and 8.88 diameters. Attached to the index bar is a finding level, which saves much time and trouble in picking up the reflected image of an object.

Owing to my severe and protracted illness in Scotland, I have not had time to make any investigation of the error of eccentricity of this sextant since my return. In reducing the observations, I have therefore employed the errors determined in 1869, which are given in the following table; ω is the reading on the arc and E the corresponding correction for eccentricity.

ω	E	ω	E	ω	E
°	″	°	″	°	″
0	0.0	50	+ 8.1	100	+19.9
10	+ 1.2	60	10.2	110	22.6
20	2.6	70	12.5	120	25.3
30	4.3	80	14.9	130	28.0
40	+ 6.1	90	+17.4	140	+30.8

A Mercurial Artificial Horizon, marked Ha. 1, having a folding roof, and an iron trough three inches wide by five inches long. A very careful investigation of the errors of this horizon, made by reflecting the pole star from it, and observing the reflected image with the mural circle, showed that the maximum error which can be produced in the mean of a set of observed double altitudes by omitting to reverse the roof, is only 0″.24.

A Pocket Sextant, made by Stackpole & Brother, of New York, marked No. 346, having an arc of two and a quarter inches radius, and reading to single minutes.

A Black Glass Artificial Horizon, four inches long by three inches wide, provided with a very sensitive level and an inclined plane, with black glass surfaces, which can be set on the horizon for the purpose of measuring zenith distances ranging between seventy and one hundred and thirty degrees.

A Prismatic Compass, having colored glasses for the purpose of observing the sun, and a needle three inches long, carrying a metal circle three inches in diameter, divided to single degrees.

A Small Reflecting Level.

Two Pocket-Compasses.

A fifty-foot Chesterman's Metallic Tape-Measure, which had been carefully tested by a standard, and was found to be too long in the proportion of 100.134 to 100.000.

A Binocular Field-Glass, magnifying 5.50 diameters, and having a field of view of 2° 50′.

A Pocket Achromatic Telescope, having an object-glass made by Alvan Clark & Sons, of 9.99 inches focal length and 1.09 inches clear aperture, with a terrestrial eye-piece magnifying 19.2 diameters and a field of view of 1° 48′; provided with a screw clip for holding it steadily while observing.

A set of three Colored Glasses, mounted in a german-silver frame, for the pocket.

A Pocket Aneroid Barometer, 1.9 inches in diameter, made by L. Casella, of London, and marked No. 1128. It has a scale extending from 23 to 31 inches, graduated to 0.05 of an inch, and is compensated for temperature.

Two Pocket Thermometers.

A Rain Gauge, having a receiving surface 2.788 inches in diameter, and a glass measure for the same, holding fifty cubic centimeters and graduated to half a cubic centimeter—each half cubic centimeter being equal to 0.005 of an inch of rain.

A set of Drawing Instruments.

We had with us, for the use of the party, four excellent mean time box chronometers, made by T. S. & J. D. Negus, of New York. They were marked numbers 1115, 1228, 1256, and 1340.

I had also a number of books and other articles, a full list of which is given in Addendum C to this report.

IV.—PROBABLE ERROR OF OBSERVATIONS MADE WITH A SEXTANT.

As the sextant is a very portable and convenient instrument, and is much used for scientific purposes, it seems worth while to determine carefully what degree of accuracy may be expected in observations made with it. For that purpose I have collected in the following table nearly all the data which can be derived from the work of the officers of this Observatory in connection with the total solar eclipses of August, 1869, and December, 1870. It is to be understood that each set of altitudes consists of six readings, the object being observed in a mercurial artificial horizon, with a sextant whose telescope magnifies about nine diameters, and whose vernier reads to ten seconds; and further, that with each set of six altitudes, the index correction has been determined by six readings made for that purpose.

TABLE I.

Observer.	Station.	Object of Observations.	Object Observed.	No. of sets of Altitudes.	Probable Error of Time.	Probable Error of Altitude.
					s.	″
Harkness . .	Des Moines. . .	Latitude .	Sun . .	16		±3.89
Hall	Siberia	Latitude .	Sun . .	13		3.16
Rogers . . .	Siberia	Latitude .	Sun . .	6		2.47
Harkness . .	Syracuse. . . .	Latitude .	Sun . .	11		2.98
Hall	Syracuse and Malta	Latitude .	Sun . .	11		3.12
Harkness . .	Des Moines. . .	Time . .	Sun . .	20	±0.145	1.63
Harkness . .	Syracuse. . . .	Time . .	Sun . .	38	.321	2.59
Hall	Syracuse and Malta	Time . .	Sun . .	40	.381	3.05
Harkness . .	Des Moines. . .	Latitude .	Polaris .	3		6.85
Harkness . .	Syracuse. . . .	Latitude .	Polaris .	6		8.29
Hall	Syracuse. . . .	Latitude .	Polaris .	3		3.45

In the case of the time observations given in the above table, the average azimuths were as follows, namely: at Des Moines, 90°; at Syracuse, 42° 27′; at Syracuse and Malta, 42°.

The observations of the sun give the following results: 57 sets of altitudes, observed to determine latitude, give for the probable error of the mean of a single set $\pm$ 3''.25; and 98 sets of altitudes, observed to determine local time, give for the probable error of the mean of a single set $\pm$ 2''.58. The arithmetical mean of these two values is $\pm$ 2''.92. I therefore adopt as the probable error of the mean of a set of six altitudes of the sun $\pm$ 3''.00 — a result which rests on no less than 930 observed altitudes.

The number of observations on stars, contained in Table I, is not sufficiently great to render it possible to determine a reliable probable error from them, but it is evident that the probable error of an observation of a star is greater than that of an observation of the sun.

To an officer in the field desirous of determining local time, it is a matter of importance to know precisely at what hour angle it will be most advantageous to observe. I have therefore constructed the following table, which will enable a person in any latitude, and with the sun at any declination, to ascertain almost at a glance the altitude, azimuth, and hour angle when the sun is in the most favorable position for time observations. The numerical computations for the table have been made by Mr. Ormond Stone, and in constructing it I have assumed that the altitudes must be confined between sixteen and seventy degrees, these being about the limits of convenient observation with a sextant. δ is the sun's declination.

TABLE II.

Latitude and Declination of the same name.

Latitude.	$\delta = 23°.5$ Altitude.	$\delta = 23°.5$ Azimuth.	$\delta = 23°.5$ Hour Angle.	$\delta = 20°.0$ Altitude.	$\delta = 20°.0$ Azimuth.	$\delta = 20°.0$ Hour Angle.	$\delta = 15°.0$ Altitude.	$\delta = 15°.0$ Azimuth.	$\delta = 15°.0$ Hour Angle.	$\delta = 10°.0$ Altitude.	$\delta = 10°.0$ Azimuth.	$\delta = 10°.0$ Hour Angle.	$\delta = 5°.0$ Altitude.	$\delta = 5°.0$ Azimuth.	$\delta = 5°.0$ Hour Angle.
°	°	°	h.m.	°	°	h.m.	°	°	h.m.	°	°	h.m.	°	°	h.m.
0	16.0	115.5	4 50	16.0	110.8	4 52	16.0	105.6	4 54	16.0	100.4	4 55	16.0	95.2	4 56
5	16.0	113.0	4 58	16.0	109.4	4 59	19.7	104.2	4 44	30.1	98.6	4 1	70.0	90.8	1 20
10	25.8	111.4	4 24	30.5	107.4	4 4	42.1	101.3	3 16	70.0	91.8	1 22	30.1	90.0	4 1
15	40.5	108.3	3 28	49.2	103.3	3 10	70.0	92.7	1 23	42.1	90.0	3 16	19.7	90.0	4 44
20	59.1	102.6	2 13	70.0	93.7	1 25	49.2	90.0	2 50	30.5	90.0	4 4	16.0	89.6	4 59
25	70.7	90.0	1 24	54.0	90.0	2 35	37.8	90.0	3 40	24.3	90.0	4 31	16.0	88.1	4 59
30	52.8	90.0	2 44	43.2	90.0	3 24	31.2	90.0	4 9	20.3	90.0	4 49	16.0	86.5	4 57
35	44.0	90.0	3 26	36.7	90.0	3 55	26.8	90.0	4 30	17.6	90.0	5 2	16.0	84.8	4 56
40	38.4	90.0	3 55	32.2	90.0	4 17	23.7	90.0	4 46	16.0	89.7	5 10	16.0	82.9	4 53
45	34.3	90.0	4 9	29.0	90.0	4 35	21.5	90.0	4 58	16.0	88.4	5 9	16.0	80.9	4 49
50	31.3	90.0	4 34	26.5	90.0	4 49	19.7	90.0	5 8	16.0	86.6	5 8	16.0	78.5	4 44
55	29.1	90.0	4 49	24.7	90.0	5 1	18.6	90.0	5 17	16.0	84.6	5 5	16.0	75.5	4 36
60	27.4	90.0	5 2	23.3	90.0	5 12	17.6	90.0	5 24	16.0	82.2	5 1	16.0	71.6	4 25
65	26.1	90.0	5 13	22.7	90.0	5 21	16.6	90.0	5 31	16.0	79.3	4 54	16.0	66.4	4 9
70	25.1	90.0	5 24	21.3	90.0	5 30	16.0	90.0	5 38	16.0	74.9	4 42	16.0	58.5	3 41
75	24.4	90.0	5 33	20.7	90.0	5 38	16.0	88.3	5 36	16.0	68.1	4 20	16.0	44.0	2 48
80	23.9	90.0	5 42	20.3	90.0	5 45	16.0	85.7	5 32	16.0	54.2	3 29			
85	23.6	90.0	5 51	20.1	90.0	5 53	16.0	79.2	5 11						

Declination, 0°.0, and Latitude and Declination of different name.

Declination, 0°.0 Altitude.	Declination, 0°.0 Azimuth.	Declination, 0°.0 Hour Angle.	$\delta = 5°.0$ Altitude.	$\delta = 5°.0$ Azimuth.	$\delta = 5°.0$ Hour Angle.	$\delta = 10°.0$ Altitude.	$\delta = 10°.0$ Azimuth.	$\delta = 10°.0$ Hour Angle.	$\delta = 15°.0$ Altitude.	$\delta = 15°.0$ Azimuth.	$\delta = 15°.0$ Hour Angle.	$\delta = 20°.0$ Altitude.	$\delta = 20°.0$ Azimuth.	$\delta = 20°.0$ Hour Angle.	$\delta = 23°.5$ Altitude.	$\delta = 23°.5$ Azimuth.	$\delta = 23°.5$ Hour Angle.	Latitude.
°	°	h.m.	°	°	h.m.	°	°	h.m.	°	°	h.m.	°	°	h.m.	°	°	h.m.	°
70.0	90.0	1 20	16.0	84.8	4 56	16.0	79.6	4 55	16.0	74.4	4 54	16.0	69.2	4 52	16.0	64.5	4 50	0
16.0	88.6	4 56	16.0	83.4	4 54	16.0	78.2	4 51	16.0	72.8	4 48	16.0	67.6	4 44	16.0	63.8	4 40	5
16.0	87.1	4 55	16.0	81.9	4 51	16.0	76.6	4 46	16.0	71.1	4 41	16.0	65.7	4 35	16.0	61.9	4 30	10
16.0	85.6	4 54	16.0	80.2	4 48	16.0	74.7	4 41	16.0	69.2	4 34	16.0	63.6	4 26	16.0	59.6	4 19	15
16.0	84.1	4 52	16.0	78.4	4 44	16.0	72.8	4 35	16.0	67.0	4 26	16.0	61.1	4 14	16.0	56.9	4 6	20
16.0	82.3	4 49	16.0	76.5	4 39	16.0	70.6	4 28	16.0	64.5	4 16	16.0	58.3	4 2	16.0	53.8	3 51	25
16.0	80.5	4 46	16.0	74.3	4 33	16.0	68.1	4 20	16.0	61.5	4 4	16.0	54.8	3 47	16.0	49.9	3 33	30
16.0	78.6	4 41	16.0	71.8	4 26	16.0	65.1	4 9	16.0	58.0	3 50	16.0	50.6	3 29	16.0	45.0	3 11	35
16.0	76.2	4 36	16.0	69.0	4 17	16.0	61.6	3 56	16.0	53.7	3 33	16.0	45.2	3 6	16.0	38.6	2 43	40
16.0	73.3	4 28	16.0	65.5	4 6	16.0	57.2	3 40	16.0	48.1	3 11	16.0	37.8	2 35	16.0	29.2	2 3	45
16.0	70.1	4 18	16.0	61.1	3 51	16.0	51.5	3 19	16.0	40.5	2 41	16.0	22.5	1 32	16.0	9.2	0 39	50
16.0	65.8	4 5	16.0	55.4	3 30	16.0	43.6	2 49	16.0	28.5	1 53							55
16.0	60.2	3 46	16.0	47.3	3 1	16.0	31.0	2 0										60
16.0	52.1	3 17	16.0	33.9	2 16													65
16.0	38.0	2 25																70
																		75
																		80
																		85

If we let

$d\zeta$ = probable error of an observed zenith distance, expressed in seconds of arc,
dt = probable error of the corresponding hour angle, expressed in seconds of time,
φ = latitude of the place of observation,
A = azimuth of the sun at the time of observation,

then we shall have

$$dt = \frac{d\zeta}{15 \cos\varphi \, . \, \sin A}$$

by means of which formula I have computed Table III. The azimuths have been taken from Table II, and $d\zeta$ has been assumed equal to $\pm\, 3''.00$.

TABLE III.—*Probable Error of a Chronometer Correction determined from the mean of Six Double Altitudes of the Sun, observed, when in the most favorable position, by means of a Sextant.*

Latitude.	Latitude and Declination of the same name.					Declination, 0°	Latitude and Declination of different name.					Latitude.
	$\delta=23°.5$	$\delta=20°$	$\delta=15°$	$\delta=10°$	$\delta=5°$		$\delta=5°$	$\delta=10°$	δ 15°	$\delta=20°$	$\delta=23°.5$	
°	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	°
0	±0.22	±0.21	±0.21	±0.20	±0.20	±0.20	±0.20	±0.20	±0.21	±0.21	±0.22	0
5	.22	.21	.21	.20	.20	.20	.20	.21	.21	.22	.22	5
10	.22	.21	.21	.20	.20	.20	.21	.21	.21	.22	.23	10
15	.22	.21	.21	.21	.21	.21	.21	.21	.22	.23	.24	15
20	.22	.21	.21	.21	.21	.21	.22	.22	.23	.24	.25	20
25	.22	.22	.22	.22	.22	.22	.23	.23	.24	.26	.27	25
30	.23	.23	.23	.23	.23	.23	.24	.25	.26	.28	.30	30
35	.24	.24	.24	.24	.24	.25	.26	.27	.29	.32	.35	35
40	.26	.26	.26	.26	.26	.27	.28	.30	.32	.37	.42	40
45	.28	.28	.28	.28	.29	.30	.31	.34	.38	.46	0.58	45
50	.31	.31	.31	.31	.32	.33	.36	.40	.48	0.81	1.94	50
55	.35	.35	.35	.35	.36	.38	.42	.51	0.73			55
60	.40	.40	.40	.40	.42	.46	.54	0.78				60
65	.47	.47	.47	.48	.52	.60	0.85					65
70	.58	.58	.58	.61	0.69	0.95						70
75	0.77	0.77	0.77	0.83	1.11							75
80	1.15	1.15	1.15	1.42								80
85	2.30	2.30	2.34									85

Putting

r = probable error of a single set of observations,
r_0 = probable error of arithmetical mean of m sets of observations,
c = constant error affecting each set of observations,
p_m = weight of the arithmetical mean of m sets of observations,

we have

$$r_0 = \frac{r}{p_m}$$

It is usual to assume p_m proportional to $\sqrt{m}$; but, inasmuch as experience shows that in the case of every instrument there is a limit beyond which increasing the number of observations adds almost nothing to the accuracy of the final result, I have preferred to follow the principles laid down by Dr. B. A. Gould

in his discussion of the weights and mean errors of the observations of Mars and Venus made during the years 1849–'52, and employed to determine the solar parallax.* In accordance with these principles, putting

$$c = ar \qquad\qquad b = \frac{1}{a^2} = \frac{r^2}{c^2}$$

we find

$$p = m \cdot \frac{b+1}{m+b}$$

b depends solely upon the quality of the observations employed, and increases in the ratio of their accuracy, so that b^2 sets of observations are worth b times as much as one set, but no finite number of sets can ever be worth $b + 1$ times as much as one set. The numerical value of b is arbitrary. For sextant work the observations which I have been able to examine seem to indicate as the most probable value, $b = 3$. That I have adopted, and by substituting it in the formula for p_m, given above, I have computed Table IV.

TABLE IV.—*Weights as Functions of the Number of Observations.*

No.	Weight.	No.	Weight.	No.	Weight.	No.	Weight.	No.	Weight.
1	1.00	6	2.67	12	3.20	25	3.57	50	3.77
2	1.60	7	2.80	14	3.29	30	3.64	60	3.81
3	2.00	8	2.91	16	3.37	35	3.68	75	3.85
4	2.29	9	3.00	18	3.43	40	3.72	100	3.88
5	2.50	10	3.08	20	3.48	45	3.75	1000	3.99

By means of the weights contained in Table IV, I have computed Table V, which, with the argument "Probable error of a single set of observations" gives the probable error of the arithmetical mean of any number of sets of observations not greater than 100. The figures placed at the head of each column indicate the number of sets of observations to the mean of which the probable errors contained in that column apply. The table is used by entering the column headed "1" with the known probable error of a single set of observations; then, on the same line with this known probable error, in the column headed "2" will be found the probable error of the arithmetical mean of two sets of observations; in the column headed "3," the probable error of the arithmetical mean of three sets of observations; and so on for each of the other columns.

* United States Naval Astronomical Expedition to the Southern Hemisphere, Vol. III, page cclii.

TABLE V.—*Probable Error of the Mean of several sets of Sextant Observations, expressed as a Function of the number of sets, there being Six Observed Altitudes in each set.*

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]	±[illegible]
s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

In order to meet cases where more or less than six altitudes have been observed in each set, I have made use of the weights contained in Table IV to compute Table VI, which, with the argument "Probable error of the mean of six altitudes" gives the probable error of the mean of various numbers of altitudes, ranging between 1 and 20. The arrangement of this table is similar to that of Table V.

TABLE VI.—*Probable Error of the Mean of a set of Sextant Observations, expressed as a Function of the number of Observed Altitudes.*

6	1	2	3	4	5	8	10	12	14	16	18	20
"	"	"	"	"	"	"	'	"	"	"	"	"
± 3.00	± 8.01	± 5.01	± 3.99	± 3.48	± 3.21	± 2.75	± 2.60	± 2.50	± 2.43	± 2.37	± 2.33	± 2.30
s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
0.20	0.53	0.33	0.27	0.23	0.21	0.18	0.17	0.17	0.16	0.16	0.16	0.15
.22	.59	.37	.29	.26	.24	.20	.19	.18	.18	.17	.17	.17
.24	.64	.40	.32	.28	.26	.22	.21	.20	.19	.19	.19	.18
.26	.69	.43	.35	.30	.28	.24	.23	.22	.21	.21	.20	.20
.28	.75	.47	.37	.32	.30	.26	.24	.23	.23	.22	.22	.21
.30	.80	.50	.40	.35	.32	.27	.26	.25	.24	.24	.23	.23
.32	.85	.53	.43	.37	.34	.29	.28	.27	.26	.25	.25	.25
.34	.91	.57	.45	.39	.36	.31	.29	.28	.28	.27	.26	.26
.36	0.96	.60	.48	.42	.39	.33	.31	.30	.29	.28	.28	.28
.38	1.01	.63	.51	.44	.41	.35	.33	.32	.31	.30	.30	.29
.40	.07	.67	.53	.46	.43	.37	.35	.33	.32	.32	.31	.31
.45	.20	.75	.60	.52	.48	.41	.39	.38	.36	.36	.35	.34
.50	.33	0.84	.66	.58	.54	.46	.43	.42	.41	.40	.39	.38
.60	1.60	1.00	0.80	.70	.64	.55	.52	.50	.49	.47	.47	.46
0.80	2.14	.34	1.06	0.93	0.86	.73	.69	.67	.65	.63	.62	.61
1.00	2.67	1.67	1.33	1.16	1.07	0.92	0.87	0.83	0.81	0.79	0.78	0.77
1.50	4.00	2.50	2.00	1.74	1.60	1.37	1.30	1.25	1.22	1.19	1.17	1.15
2.00	5.34	3.34	2.66	2.32	2.14	1.83	1.73	1.67	1.62	.58	.56	.53
2.50	6.68	4.18	3.32	2.90	2.68	2.29	2.16	2.08	2.03	1.98	1.94	1.92

Of course these tables apply only to the probable accidental errors, and afford no clew whatever to the constant errors. In order to get rid of the latter a special investigation must be made for the instrument employed, or else care must be taken to make all the observations in pairs, upon objects at about equal altitudes on each side of the zenith. Table VI shows that almost nothing is gained by observing more than six altitudes in each set, and Table V shows that there is very little use in making more than ten sets of observations for any one object. That is, supposing the constant errors to be entirely eliminated, a latitude depending upon the mean of ten good sets of meridian altitudes is as trustworthy as any that can be found from observations with a sextant; and a chronometer correction depending upon the mean of three sets of altitudes observed to the east, and an equal number observed to the west, of the meridian, the sun being at about the same altitude in each case, is as reliable as any that can be obtained by means of a sextant.

V.—GENERAL REMARKS ON THE OBSERVATIONS FOR TIME AND LATITUDE.

The observations for time and latitude were all made by me, assisted usually by Professor Eastman, who noted the time at a given signal, and then recorded the observation. On two or three occasions I was assisted by Professor Hall, and again by Captain G. L. Tupman. In the first observation that I made at Syracuse I attempted to take up the beat of the chronometer and note the times myself, but I soon abandoned that plan because, owing to noise and other disturbing influences, it did not seem either so accurate or so convenient as to have the times noted by an assistant. The instruments employed were the sextant Stackpole and Brother, No. 937, with a magnifying power of 8.88 diameters on its telescope; the mercurial artificial horizon Ha. 1; and the mean time box chronometer T. S. and J. D. Negus, No. 1115. When observing the sun, half the altitudes were always measured on one limb, with the roof of the artificial horizon in one position, and the other half of the altitudes were measured on the other limb, with the roof of the horizon reversed. When observing stars half the altitudes were measured with the roof in one position, and the other half with it reversed. In the day-time the index correction of the sextant was determined by measuring the diameter of the sun both on and off the arc; at night it was determined by observing the contact of the direct and reflected image of a star.

Throughout this report civil dates are employed. The refractions have been computed by means of Bessel's formula, using the tables given in the Appendix to the Washington Observations for 1845. For latitude observations the tabular part of the reductions to the meridian has been taken from Loomis's Practical Astronomy. All astronomical data required in the reductions have been taken from the American Ephemeris and Nautical Almanac. For further details as to the mode of observing, the formulæ employed in the reductions, &c., reference may be made to my Report on the Total Solar Eclipse of August 7, 1869.*

VI.—OBSERVATIONS FOR TIME.

The observations for time are given in detail in Addendum A to this report, but for convenience of reference the following abstract of them is inserted here. The first column of the table contains the dates; the second column contains the corrections to the chronometer derived from the individual sets of observations made in the forenoon; the third column contains the corrections derived from the sets of observations made in the afternoon; the fourth column contains for each day the mean of the corrections given by the forenoon observations; the fifth column contains for each day the mean of the corrections given by the afternoon observations; the sixth column contains for each day the mean of the numbers given in the fourth and fifth columns, which is taken to be the correction to the chronometer at noon; the seventh column contains the resulting daily rates. The observations on the morning of December 13 were made at the Prima Porta Terra, $0^s.13$ east of the Stone Gun-Platform, but in computing the correction to the chronometer at noon of that day the necessary allowance has been made to reduce them to the Stone Gun-Platform.

* Appendix II to the Washington Observations for 1867, pp. 33-40.

Chronometer T. S. & J. D. Negus No. 1115 slow of Mean Time at the Stone Gun-Platform, Syracuse, by observation.

Date.	A. M.	P. M.	Means.		Correction at Noon.	Daily Rate.
			A. M.	P. M.		
1870.	h. m. s.	s.	s.	s.	h. m. s.	s.
December 13	+ 1 2 42.9	42.9				
	43.8	43.1	43.47*	43.00	+ 1 2 43.17	
	43.7					
						+ 0.70
14	42.8	44.2				
	43.9	44.3	43.77	43.97	43.87	
	44.6	43.4				
						0.49
15	43.8	44.7				
	45.1	43.8	44.50	44.23	44.36	
	44.6	44.2				
						0.32
16	43.8	44.2				
	45.3	44.3	44.80	44.57	44.68	
	45.3	45.2				
						0.21
19	46.1	44.4				
	45.8	44.5	46.07	44.53	45.30	
	46.3	44.7				
						+ 0.12
21	45.4	44.9				
	46.7	44.5	46.37	44.70	45.54	
	47.0	44.7				
22	45.6					
	45.3		45.13		+ 1 2 45.14	
	+ 1 2 44.5					

* $0^s.13$ to the east of Stone Gun-Platform.

At the time of the eclipse, on December 22, I have taken this chronometer to be $1^h\ 2^m\ 45^s.7$ slow of mean time at the Stone Gun-Platform.

The following table contains all the chronometer comparisons made while we were at Syracuse, and I desire to call particular attention to the remarkably good running of the chronometers No. 1115 and No. 1256. Such a result shows the great degree of perfection to which the manufacture of these instruments has been carried.

The chronometer French No. 21778 belonged to Mr. Brothers, ot the English Expedition, and was used by him in timing the exposures of his photographic plates. It had a losing rate of about six seconds per day.

Chronometer Comparisons made at Syracuse.

Date.	Negus 1115.	Negus 1228.	Negus 1340.	Negus 1256.
1870.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
December 13	3 16 0		3 19 22.0	3 17 39.4
14	9 21 0		9 24 23.2	9 22 39.5
14	2 50 0		2 53 24.2	2 51 39.7
15	8 31 0		8 34 25.7	8 32 39.7
15	2 23 0		2 26 26.0	2 24 39.7
16	8 8 0		8 11 28.2	8 9 39.7
16	2 28 0		2 31 28.2	2 29 39.7
17	11 18 0	11 20 5.7	11 21 30.0	11 19 39.8
19	11 15 0	11 17 6.3	11 18 33.2	11 16 40.0
21	11 28 0	11 30 6.5	11 31 37.5	11 29 40.1
22	9 2 0	9 4 7.2	9 5 39.2	9 3 40.2
22	2 30 0	2 32 7.2	2 33 39.8	2 31 40.4
		French 21778.		
		h. m. s.		
22	8 57 0	8 54 47.1		
22	2 53 0	2 50 45.5		

VII.—OBSERVATIONS FOR LATITUDE.

The observations for latitude are given in detail in Addendum B to this report; but for convenience of reference the following abstract of them is inserted here.

Abstract of Results of Observations for Latitude of the Stone Gun-Platform at Syracuse.

Date.	Object.	Latitude.
1870.		° ′ ″
December 13	Sun	+37 3 63
14	Polaris	66
14	Polaris	47
16	Sun	56
16	Sun	58
16	Polaris	37
16	Polaris	43
17	Sun	63
17	Sun	53
18	Sun	62
18	Sun	63
19	Sun	52
19	Sun	57
19	Polaris	54
19	Polaris	67
21	Sun	63
21	Sun	64

Taking separately the mean of the latitudes resulting from observations on the sun, and the mean of the latitudes resulting from observations on Polaris, I find

	°	′	″	″
From the Sun	+ 37	3	59.4	± 0.90
From Polaris			52.3	± 3.38
Mean	+ 37	3	55.9	

As the value from the sun, and that from Polaris, differ from each other by more than the square root of the sum of the squares of their probable errors, I infer that they are affected by a small constant error, and I therefore take their mean as the value of the latitude to be derived from my observations.

Professor Hall's observations at Syracuse, reduced by himself, give for the value of the latitude

	°	′	″
From the Sun	+ 37	3	59.7
From Polaris			35.0
Mean	+ 37	3	47.3

My result for latitude depends on one hundred and two observed altitudes; Professor Hall's on sixty-four observed altitudes. Giving each determination weight in proportion to the number of altitudes on which it depends, I get finally for the latitude of the Stone Gun-Platform

$$+ 37^\circ\ 3'\ 52''.6 \pm 2''.98$$

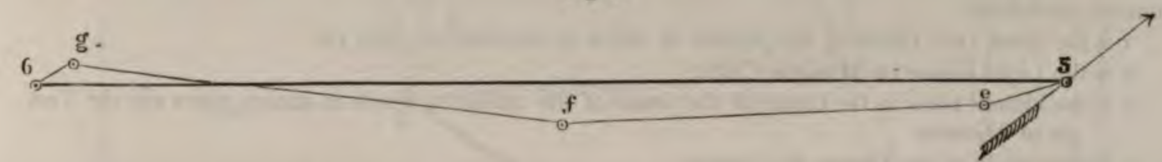
and that value I adopt.

VIII.—TRIANGULATION AT SYRACUSE.

In order to connect our observing station at the Stone Gun-Platform with the various conspicuous landmarks in the city of Syracuse, it was necessary to make a small triangulation.

On passing out of the city toward the main-land, about one-eighth of a mile (200 meters) beyond the fortifications, we come to an open circular space perhaps three hundred feet (98 meters) in diameter. From

Fig. 4.



this circular space four roads radiate. That directed N. 82° W. (true) leads to Avola and Noto. Traveling along it for a little more than half a mile (860 meters) we come to a small stream, crossed by a substantial stone bridge of three arches. Continuing in the same direction about seven-eighths of a mile (1,390 meters) further we come to another fine stone bridge, which, in this case, consists of a single arch spanning the Anapus River. The land between these two bridges is low and marshy, and the road is an artificial causeway protected throughout nearly its whole length by a stone wall on its eastern side. This wall rises about three feet above the surface of the road, and its top is covered with heavy coping-stones. On these coping-stones Professor Hall and I measured the base-line which is shown on a scale of 1 to 10,000 in Figure 4. The causeway was not quite straight, which obliged us to measure the base in four sections; the northern terminus, 5, Fig. 4, being directly above the key-stone in the east face of the central arch of the three-arched bridge; and the southern terminus, 6, Fig. 4, being directly above the key-stone in the east face of the arch over the Anapus River. The measurements were made on December 20, with my Chesterman's metallic tape-line, which is too long in the proportion of 100.134 to 100.000. This explains

the origin of the column, "Corrected distances," in the following table giving the details of the measurement of the base-line:

Stations.	Measured Distances in Feet.	Corrected Distances in Feet.	Corrected Distances in Meters.
From 5 to *e* . .	372.58	372.08	113.41
From *e* to *f* . .	1850.00	1847.52	563.15
From *f* to *g* . .	2150.00	2147.12	654.47
From *g* to 6 . .	187.75	187.50	57.15
	Observed Angles.		
	° ′		
5 *e f*	166 5		
e f g	170 30		
f g 6	144 56		

The following table gives the results of the successive steps in reducing this base to a straight line:

Stations.	Angles.	Distances in Feet.	Distances in Meters.
	° ′ ″		
5 *e f*	166 5 0		
From 5 to *f* . . .		2210.51	673.79
5 *f g*	168 10 47		
From 5 to *g* . . .		4334.28	1321.14
5 *g* 6	150 55 48		
From 5 to 6 . . .		4499.09	1371.38

On December 20 and 21, Professor Hall and I executed, upon this base, the triangulation shown in Fig. 5, which is drawn on a scale of 1 to 15,000. The different stations are designated in the figure by numerals, as follows:

1 is the Stone Gun-Platform, the position of which is described on page 48.

2 is the Light-House on Maniace Castle.

3 is the highest point in the center of the *façade* of the cathedral, which in ancient times was the Temple of Minerva.

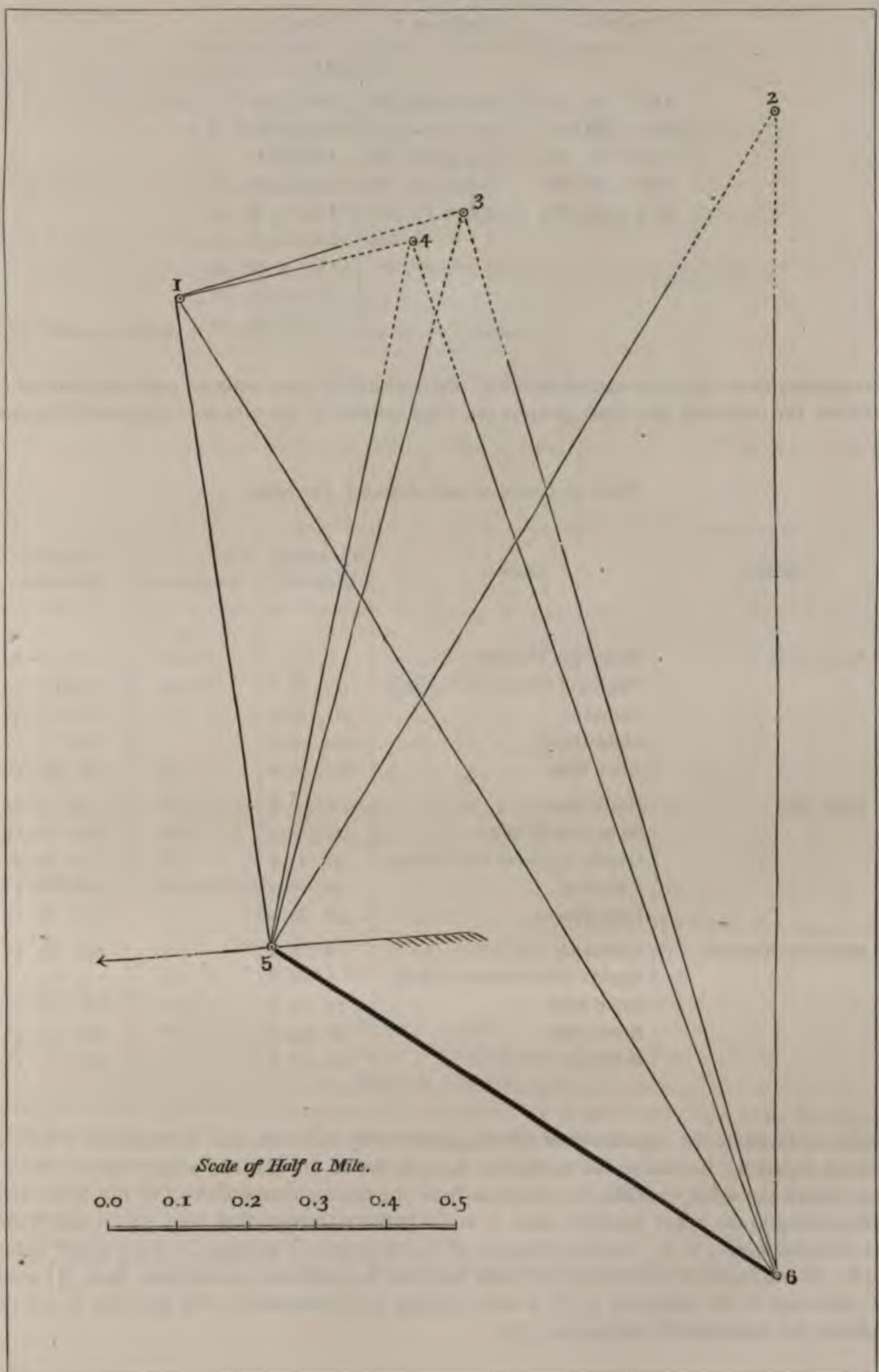
4 is the cupola of the Chiesa del Collegio.

5 is the north end of the base, which is directly above the key-stone in the east face of the central arch of the three-arched bridge.

6 is the south end of the base, which is directly above the key-stone in the east face of the arch of the bridge over the Anapus River.

7 is the Belvedere Tower, which is not shown in the figure.

Fig. 5.



By means of my pocket sextant, Stackpole & Brother, No. 346, the following angles were measured:

Angles at 1.	Angles at 5.	Angles at 6.
° ′	° ′	° ′
6 1 5 = 23 9	1 5 2 = 39 11	1 6 2 = 31 14
3 1 5 = 98 24	1 5 3 = 22 45	1 6 3 = 15 2
4 1 5 = 95 13	1 5 4 = 19 25	1 6 4 = 12 0
5 1 7 = 25 24	3 5 2 = 16 16	3 6 2 = 16 12
6 1 7 = 48 32	4 5 2 = 19 40	4 6 2 = 19 12
	4 5 3 = 3 24	4 6 3 = 3 2
	2 5 6 = 92 20	5 6 2 = 56 40
		5 6 1 = 25 27
		5 6 3 = 40 29

By correcting these angles in accordance with the method of least squares, and then converting them into directions, the corrected directions given in the third column of the subjoined table were obtained.

Table of Corrected and Adjusted Directions.

Station.	Object.	Corrected Direction.	Correction by Adjustment.	Adjusted Direction.
		° ′	′	° ′ ″
North Base	Stone Gun-Platform . . .	0 0.0	+0.48	0 0 29
	Cupola of Chiesa del Collegio	19 25.5	− .25	19 25 15
	Cathedral	22 48.5	+ .10	22 48 36
	Light-House	39 7.0		39 7 0
	South Base	131 27.0	− .33	131 26 40
South Base	North Base	0 0.0	+ .38	0 0 22
	Stone Gun-Platform . . .	25 26.9	− .61	25 26 17
	Cupola of Chiesa del Collegio	37 27.4	+ .36	37 27 46
	Cathedral	40 28.9	− .12	40 28 47
	Light-House	56 40.3		56 40 18
Stone Gun-Platform .	Cathedral	0 0.0	− .02	359 59 59
	Cupola of Chiesa del Collegio	3 11.0	+ .04	3 11 2
	South Base	75 15.5	+ .29	75 15 47
	North Base	98 24.0	−0.31	98 23 41
	Belvedere Tower	123 47.8		123 47 48

In order to facilitate the adjustment of this triangulation by the method of least squares, I have adopted the following notation: Retaining the numerical designation of the stations already given, two numbers written one above the other indicate the direction from the station corresponding to the lower number to that corresponding to the upper number; thus, $\genfrac{}{}{0pt}{}{1}{5}$ would indicate the direction from 5 to 1, and $\genfrac{}{}{0pt}{}{6}{5}$ would indicate the direction from 5 to 6. As the difference of two directions is an angle, $-\genfrac{}{}{0pt}{}{1}{5}+\genfrac{}{}{0pt}{}{6}{5}$ would indicate the angle 1 5 6. If the numbers are inclosed between brackets they indicate a correction; thus, $[\genfrac{}{}{0pt}{}{1}{5}]$ would indicate the correction to the direction $\genfrac{}{}{0pt}{}{1}{5}$; $[\genfrac{}{}{0pt}{}{6}{5}]$ would indicate the correction to the direction $\genfrac{}{}{0pt}{}{6}{5}$, and $[-\genfrac{}{}{0pt}{}{1}{5}+\genfrac{}{}{0pt}{}{6}{5}]$ would indicate the correction to the angle 1 5 6.

Proceeding in the usual manner,* the quadrilateral 1 4 6 5 furnishes the angle equation

$$180^\circ = 5\,1\,6 + 1\,6\,5 + 6\,5\,1$$

and the side equation

$$\sin 1\,5\,4 \,.\, \sin 5\,6\,4 \,.\, \sin 4\,1\,6 = \sin 4\,1\,5 \,.\, \sin 4\,5\,6 \,.\, \sin 1\,6\,4$$

from which we derive the equations of condition

$$0 = +2.4 - \genfrac{[}{]}{0pt}{}{6}{1} + \genfrac{[}{]}{0pt}{}{5}{1} - \genfrac{[}{]}{0pt}{}{5}{6} + \genfrac{[}{]}{0pt}{}{1}{6} - \genfrac{[}{]}{0pt}{}{1}{5} + \genfrac{[}{]}{0pt}{}{6}{5} \qquad \text{I.}$$

$$\begin{aligned} 0 = +83.3 &- 35.8\genfrac{[}{]}{0pt}{}{1}{5} + 30.7\genfrac{[}{]}{0pt}{}{4}{5} - 16.5\genfrac{[}{]}{0pt}{}{5}{6} - 42.8\genfrac{[}{]}{0pt}{}{4}{6} - 5.2\genfrac{[}{]}{0pt}{}{4}{1} + 4.1\genfrac{[}{]}{0pt}{}{6}{1} \\ &+ 1.1\genfrac{[}{]}{0pt}{}{5}{1} + 5.1\genfrac{[}{]}{0pt}{}{6}{5} + 59.3\genfrac{[}{]}{0pt}{}{1}{6} \end{aligned} \qquad \text{II.}$$

The quadrilateral 1 3 6 5 furnishes the side equation

$$\sin 1\,5\,3 \,.\, \sin 5\,6\,3 \,.\, \sin 3\,1\,6 = \sin 3\,1\,5 \,.\, \sin 3\,5\,6 \,.\, \sin 1\,6\,3$$

from which we derive the equation of condition

$$\begin{aligned} 0 = +43.5 &- 30.0\genfrac{[}{]}{0pt}{}{1}{5} + 25.7\genfrac{[}{]}{0pt}{}{3}{5} - 14.8\genfrac{[}{]}{0pt}{}{5}{6} - 32.2\genfrac{[}{]}{0pt}{}{3}{6} - 5.2\genfrac{[}{]}{0pt}{}{3}{1} + 3.3\genfrac{[}{]}{0pt}{}{6}{1} \\ &+ 1.9\genfrac{[}{]}{0pt}{}{5}{1} + 4.3\genfrac{[}{]}{0pt}{}{6}{5} + 47.0\genfrac{[}{]}{0pt}{}{1}{6} \end{aligned} \qquad \text{III.}$$

These three equations of condition give rise to the following:

Equations of Correlatives.

v	aK_1	bK_2	cK_3
$\frac{3}{1}$			$-\ 5.2$
$\frac{4}{1}$		$-\ 5.2$	
$\frac{5}{1}$	$+\ 1$	$+\ 1.1$	$+\ 1.9$
$\frac{6}{1}$	$-\ 1$	$+\ 4.1$	$+\ 3.3$
$\frac{1}{5}$	$-\ 1$	$-\ 35.8$	$-\ 30.0$
$\frac{3}{5}$			$+\ 25.7$
$\frac{4}{5}$		$+\ 30.7$	
$\frac{6}{5}$	$+\ 1$	$+\ 5.1$	$+\ 4.3$
$\frac{1}{6}$	$+\ 1$	$+\ 59.3$	$+\ 47.0$
$\frac{3}{6}$			$-\ 32.2$
$\frac{4}{6}$		$-\ 42.8$	
$\frac{5}{6}$	$-\ 1$	$-\ 16.5$	$-\ 14.8$

The resulting normal equations are,

$$\begin{aligned} 0 &= +\ 2.4 + 6.0\,K_1 + 113.7\,K_2 + 94.7\,K_3 \\ 0 &= +83.3 + 113.7 \quad + 7915.8 \quad + 4142.8 \\ 0 &= +43.5 + 94.7 \quad + 4142.8 \quad + 5085.4 \end{aligned}$$

The solution gives

$$\begin{aligned} K_1 &= -0.306 \\ K_2 &= -0.00808 \\ K_3 &= +0.00372 \end{aligned}$$

Substituting these values in the equations of correlatives, we obtain the "Corrections by adjustment" given in the fourth column of the table of corrected and adjusted directions. Applying the corrections by adjustment to the corrected directions, we obtain the adjusted directions given in the fifth column of the same table; and by means of these adjusted directions the whole triangulation has been computed, as follows—the lengths of the sides being given in meters:

* See a paper by Charles A. Schott, esq., in the United States Coast Survey report for 1854, page 80* *et seq.*

No.	Denomination.	Observed Angles.	Corr. by Adjustment.	Plane Angles and Distances.	Logarithms.
		° ′	″		
I.	North Base—South Base			1371.4	3.13716
	Stone Gun-Platform	23 8.5	— 36	23 7 54	0.40578
	North Base	131 27.0	— 49	131 26 11	9.87488
	South Base	25 26.9	— 59	25 25 55	9.63290
	Stone Gun-Platform—South Base .			2617.1	3.41782
	Stone Gun-Platform—North Base .			1499.1	3.17584
II.	North Base—South Base			1371.4	3.13716
	Cathedral			30 53 31	0.28952
	North Base	108 38.5	— 26	108 38 4	9.97662
	South Base	40 28.9	— 29	40 28 25	9.81231
	Cathedral—South Base			2531.1	3.40330
	Cathedral—North Base			1733.8	3.23899
III.	Stone Gun-Platform—North Base .			1499.1	3.17584
	Cathedral			58 48 11	0.06784
	Stone Gun-Platform	98 24.0	— 18	98 23 42	9.99532
	North Base	22 48.5	— 23	22 48 7	9.58833
	Cathedral—North Base			1733.8	3.23900
	Cathedral—Stone Gun-Platform . .			679.2	2.83201
IV.	North Base—South Base			1371.4	3.13716
	Chiesa del Collegio			30 31 11	0.29428
	North Base	112 1.5	— 5	112 1 25	9.96709
	South Base	37 27.4	0	37 27 24	9.78402
	Chiesa del Collegio—South Base .			2503.4	3.39853
	Chiesa del Collegio—North Base .			1642.3	3.21546
V.	Stone Gun-Platform—South Base .			2617.1	3.41782
	Chiesa del Collegio			95 53 46	0.00230
	Stone Gun-Platform	72 4.5	+ 15	72 4 45	9.97840
	South Base	12 0.5	+ 59	12 1 29	9.31876
	Chiesa del Collegio—South Base .			2503.3	3.39852
	Chiesa del Collegio—Stone Gun-Pl.			548.1	2.73888
VI.	North Base—South Base			1371.4	3.13716
	Light-House			31 0 24	0.28808
	North Base	92 20.0	— 20	92 19 40	9.99964
	South Base	56 40.3	— 22	56 39 56	9.92193
	Light-House—South Base . . .			2660.0	3.42488
	Light-House—North Base . . .			2224.2	3.34717

For the determination of the azimuths of the sides of the triangles, we have the following angles, measured at the Stone Gun-Platform, late in the afternoon, between the Belvedere Tower and the sun. The instruments employed were my six-inch sextant, Stackpole & Brother No. 937, and the mean time chronometer T. S. & J. D. Negus, No. 1115.

Date.	Time by Negus 1115.	Angle between Sun and Tower.	Limb observed.
1870.	h. m. s.	° ′ ″	
December 13	2 45 4.5	59 45 20	L.
	45 58.5	59 4 30	R.
	46 35.5	58 57 30	R.
	47 20.0	59 22 10	L.
December 15	2 8 54.0	66 41 0	L.
	10 18.0	65 52 40	R.
	11 33.0	39 30	R.
	12 36.0	58 10	L.
December 16	2 15 35.5	65 31 50	L.
	16 9.0	64 54 20	R.
	16 42.5	64 48 20	R.
	17 12.0	65 13 20	L.

In order to obtain the zenith distance of the Tower, I measured with my pocket-sextant Stackpole & Brother No. 346, the angle included between the Tower and its image reflected from the inclined plane of my black-glass artificial horizon. For the reduction of these observations I have employed the formula

$$\Delta = (90^\circ + a) - \frac{m}{2}$$

in which

Δ=zenith distance of object observed,

m=angular distance between the object and its reflected image,

a=angle included between the inclined reflecting plane and a truly level surface.

In my apparatus there are two inclined black-glass reflectors, designated respectively as A and B. For A, $a=34^\circ\ 58'.8$; and for B, $a=44^\circ\ 59'.1$. When using them care was taken to place them truly at right angles to the vertical plane passing through the eye of the observer and the object to be observed. The following are the observations, together with their reduction:

Date	December 20	December 20
Inclined plane . .	A	B
	° ′	° ′
Observed values of m	72 24	92 19
	24	20
	24	21
Mean	72 24.0	92 20.0
Index Correction .	0.0	0.0
Eccentricity . . .	— 0.9	— 0.8
m	72 23.1	92 19.2
$\frac{m}{2}$	36 11.6	46 9.6
$(90^\circ+a)$	124 58.8	134 59.1
Δ	88 47.2	88 49.5

The mean of the two values of Δ is 88° 48′.4, which I have adopted.

For the determination of the sun's azimuth we have the formula

$$\tan M = \frac{\tan \delta}{\cos t} \qquad \tan A = \frac{\tan t . \cos M}{\sin (\varphi - M)}$$

where A is to be taken greater or less than 180°, according as t is greater or less than 180°.

A=azimuth of object, counted from the south around by the west.

δ=declination of object.

t=hour angle of object.

φ=latitude of place of observation.

The principal steps in the computation of the azimuth of the Tower will therefore be as follows

	December 13.			December 15.			December 16.		
	h.	m.	s.	h.	m.	s.	h.	m.	s.
Mean of Observed Times	2	46	14.6	2	10	52.5	2	16	24.8
Chronometer slow	1	2	43.3	1	2	44.4	1	2	44.7
Local Mean Time	3	48	57.9	3	13	36.9	3	19	9.5
Equation of Time	+	5	32.8	+	4	35.9	+	4	6.6
t	3	54	30.7	3	18	12.8	3	23	16.1
	°	′	″	°	′	″	°	′	″
δ	− 23	10	46	− 23	17	38	− 23	20	25
φ	+ 37	3	53	+ 37	3	53	+ 37	3	53
M	− 39	26	12	− 33	34	13	− 34	19	55
(φ−M)	+ 76	30	5	+ 70	38	6	+ 71	23	48
Sun's Azimuth	52	29	16	46	0	48	46	54	33
Mean of Observed ∠s, Sun and Tower	59	17	22	66	2	50	65	6	58
Index Correction	−		19	−		36	−		13
Corrected ∠, Sun and Tower	59	17	3	66	2	14	65	6	45
Zenith Distance of Tower	88	48	24	88	48	24	88	48	24
Zenith Distance of Sun	81	34	54	76	13	10	76	59	0
Horizontal ∠, Sun and Tower	59	6	40	65	35	47	64	42	31
Azimuth of Tower	111	35	56	111	36	35	111	37	4

Taking the mean of the three observed values, we have

	°	′	″
Azimuth from Stone Gun-Platform to Belvedere Tower	111	36	32
∠ North Base and Belvedere Tower	25	24	7
Azimuth from Stone Gun-Platform to North Base	86	12	25

The azimuths of such other of the sides as were required, together with the differences of latitude and longitude, have been computed by means of the formulæ and tables of the United States Coast Survey.* The results are appended. The columns headed "Azimuth" and "Distance" contain respectively the azimuths and distances from the stations named in the first column to those named in the sixth column. The column headed "Back Azimuth" contains the azimuths from the stations named in the sixth column to those named in the first column.

*The formulæ and tables are given in the United States Coast Survey Report for 1860, pp. 361–391. The formulæ alone are given in my Report on the Total Solar Eclipse of August 7, 1869, Appendix II to the Washington Observations for 1867, p. 57.

Table of Geographical Positions in and around Syracuse, Sicily.

Name of station.	Latitude.	Longitude.	Azimuth.	Back Azimuth.	To Station.	Distance, in Meters.	Distance, in Miles.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″			
Stone Gun-Platform	37 3 52.60	0 0 0.00	86 12 25	266 11 49	North Base	1499.1	0.93
			63 4 31	243 3 34	South Base	2617.1	1.63
North Base	37 3 49.38	+ 0 1 0.56	37 38 0	217 37 40	South Base	1371.4	0.85
			305 18 20	125 19 4	Light-House	2224.2	1.38
South Base	37 3 14.14	+ 0 1 34.45	258 6 4	78 7 5	Cathedral	2531.1	1.57
			274 17 35	94 18 40	Light-House	2660.0	1.65
Cathedral	37 3 31.06	− 0 0 5.80	109 0 36	288 59 56	North Base	1733.8	1.08
			167 48 46	347 48 43	Stone Gun-Platform	679.2	0.42
Chiesa del Collegio	37 3 35.04	− 0 0 3.47	105 37 14	285 36 35	North Base	1642.3	1.02
			170 59 48	350 59 46	Stone Gun-Platform	548.1	0.34
South Base	37 3 14.14	+ 0 1 34.45	255 5 4	75 6 3	Chiesa del Collegio	2503.4	1.55
			258 6 4	78 7 5	Cathedral	2531.1	1.57
Light-House	37 3 7.67	− 0 0 12.91	125 19 4	305 18 20	North Base	2224.2	1.38
			94 18 40	274 17 35	South Base	2660.0	1.65
Prima Porta Terra	37 3 48.06	− 0 0 1.88	161 39	341 39	Stone Gun-Platform	147.5	0.09
Mr. Brothers' Telescope	37 3 50.43	− 0 0 0.64	166 37	346 37	Stone Gun-Platform	68.9	0.04
Prof. Eastman's Telescope	37 3 51.54	− 0 0 0.31	166 37	346 37	Stone Gun-Platform	33.5	0.02
Prof. Harkness' Telescope	37 3 52.27	− 0 0 0.10	166 37	346 37	Stone Gun-Platform	10.4	0.01

IX.—TELEGRAPHIC DETERMINATION OF DIFFERENCES OF LONGITUDE.

If we let

$\Delta\lambda$ = difference of longitude between two stations; west longitudes being taken as positive;
T_e = time by face of eastern clock when it sends a signal, and
T_w = time by face of western clock when that signal is received at the western station;
T'_w = time by face of western clock when it sends a signal, and
T'_e = time by face of eastern clock when that signal is received at the eastern station;
t = time occupied in the passage of a signal from one station to the other;
ΔT_e, $\Delta T'_e$, ΔT_w, and $\Delta T'_w$ = respectively the corrections necessary to reduce the time indicated by the faces of the eastern and western clocks to true local time at the instants T_e, T'_e, T_w, T'_w;

then, neglecting personal equation, when the eastern clock sends and the signals are received at the western station, we shall have

$$\Delta\lambda - t = (T_e - T_w) + (\Delta T_e - \Delta T_w)$$

and when the western clock sends, and the signals are received at the eastern station, we shall have

$$\Delta\lambda + t = (T'_e - T'_w) + (\Delta T'_e - \Delta T'_w)$$

from which we get

$$\Delta\lambda = \frac{(T_e - T_w) + (T'_e - T'_w)}{2} + \frac{(\Delta T_e - \Delta T_w) + (\Delta T'_e - \Delta T'_w)}{2}$$

$$t = \frac{(T'_e - T'_w) - (T_e - T_w)}{2} + \frac{(\Delta T'_e - \Delta T'_w) - (\Delta T_e - \Delta T_w)}{2}$$

If the rates of the clocks are small, the second term in the expression for the value of t may usually be neglected.

Difference of Longitude between Syracuse and Malta.

The observations at Syracuse were made by me, at the Stone Gun-Platform, and have already been given in detail on page 59. The observations at Malta were made by Professor Hall, with the Pistor and Martins patent sextant No. 107, of six inches radius, a mercurial artificial horizon, and the mean time chronometer T. S. & J. D. Negus No. 1228. On December 13, he observed at Spencer's Monument; on December 14, 15, and 16, he observed on the flat roof of the Telegraph Office, which, according to the Ordnance survey map on a scale of 1 to 2500, is 6040 feet north, and 760 feet east, of Spencer's Monument. The reduction from the Telegraph Office to Spencer's Monument will therefore be, in latitude $-59''.73$, and in longitude $+9''.23 = +0^s.615$.

Professor Hall obtains from his observations the following results :*

Observations for Latitude.

Date.	Station.	Object.	No. of Altitudes.	Observed Latitude of Station.	Resulting Latitude of Spencer's Monument.
1870.				° ′ ″	° ′ ″
Dec. 13	Spencer's Monument . .	Sun . .	16	+ 35 52 55	+ 35 52 55.
14	Telegraph Office . . .	Sun . .	12	54 0	60.3
15	Telegraph Office . . .	Sun . .	8	54 23	83.3

The mean of the three results is $35° 53' 6'' \pm 5''.8$; but as a comparison of the adopted latitude of Syracuse with that obtained from Professor Hall's sextant observations shows the latter to be $7''$ too large, I subtract that amount from the mean given above, and obtain finally,

Latitude of Spencer's Monument $= +35° 52' 59'' \pm 5''.8$

*For the observations in detail see pages 30 to 38.

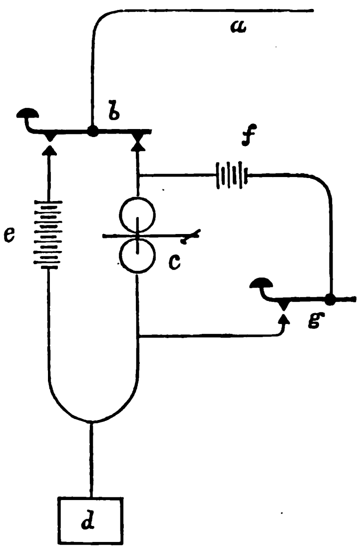
Chronometer T. S. & J. D. Negus No. 1228 slow of Local Mean Time, by Observation.

Date.	Station.	A. M.	P. M.	Correction at Noon.
1870.		h. m. s.	s.	h. m. s.
December 13	Spencer's Monument, Malta .	+0 57 29.0*		
14	Telegraph Office, Malta . .	28.4	28.6	+0 57 28.5
15	Telegraph Office, Malta . .	28.0	29.2	28.6
16	Telegraph Office, Malta . .	28.7	29.7	29.2
17	Stone Gun-Platform, Syracuse	+1 0 38.9	39.3	+1 0 39.1
18	Stone Gun-Platform, Syracuse	38.1	40.0	39.0
19	Stone Gun-Platform, Syracuse	38.6	37.8	38.2
21	Stone Gun-Platform, Syracuse	39.4	37.5	38.4
22	Stone Gun-Platform, Syracuse	37.2		

* Reduction to Telegraph Office = + 0ˢ.6.

The telegraph line between Malta and Syracuse is made up of 56½ knots = 65.1 statute miles = 104.8 kilometers of submarine cable, and 155.4 statute miles = 250 kilometers of wire stretched in the air. The total length of the line is therefore 220½ miles = 354¾ kilometers. The battery at Malta consisted of twenty small-sized Daniels cells, (Pile Callaud, Italian model,) while that at Syracuse consisted of twenty small-sized Daniels cells with the liquids in contact, known in Italy as the "Pila Callaud a strozzatura senza diaframma." The arrangement of the instruments on the line was such as is never seen in the United States, but I believe it is quite common in Europe. At each station there was a galvanic battery, *e*, Fig. 6; a polarized receiving-magnet, *c*, which recorded the signals with ink upon a long fillet of paper running at the rate of about eight-tenths of an inch per second; a transmitting-key, *b*, having a front and a back contact; and an earth-plate, *d*. The battery *e* had one of its poles connected with the earth-plate *d*, and the other attached to a point under the front contact of the key *b*. The polarized receiving-magnet *c* had one end of its coil connected with the earth-plate *d*, and the other end attached to a point under the back contact of the key *b*. The line wire *a*, coming in from the distant station, was attached to the axis of the key *b*, which, when not in use for sending signals, habitually rested on its back contact, and thus put the line to earth through the receiving-magnet *c*. Things being in this condition, any current arriving from the distant station was at once made evident by the receiving-magnet *c*. If it was desired to send a signal to the distant station, the key *b* was depressed, thus breaking the contact between the earth and the line, and establishing a connection between the latter and the battery *e*. In order to render this apparatus as convenient as possible for the exchange of longitude signals, I added to it the local battery *f* and the key *g*, connected with the receiving-magnet *c*, in the manner shown in the figure.

Fig. 6.



The following was the

PROGRAMME FOR THE DETERMINATION OF DIFFERENCE OF LONGITUDE.

1. Mean time box chronometers, beating half-seconds, will be used at each station, and their corrections and rates will be determined by means of observations on the sun, made both in the morning and in the afternoon, with sextants and mercurial artificial horizons. In order to eliminate constant errors, care will be taken that the observations in the morning and in the afternoon are made with the sun at about the same altitude; that in each case an equal number of altitudes are taken on one limb of the sun with the roof of the horizon in one position, and on the other limb of the sun with the roof of the horizon reversed; and that the index error of the sextant employed is well determined with each set of observations.

[illegible] The time of exchanging signals will necessarily depend upon the convenience of the Telegraph Company, but about 1 p. m. will [illegible] the convenience of [illegible] each day the time of exchanging signals on the day following will be agreed upon.

[illegible] signals will be exchanged in the following manner: The officer at Syracuse will ask the officer at Malta if everything is ready, and, upon receiving an affirmative reply, he will wait until his chronometer indicates 58 seconds, and then he will make a [illegible] with the key [illegible] of his apparatus. This [illegible] will consist of ten or fifteen dots, made at the rate of about five per second. Then he will make a dot [illegible] in exact coincidence with the beats of his chronometer at [illegible] seconds, and this he will continue for three minutes, ending at [illegible] seconds. Then he will pause for five seconds, and finally finish with a [illegible], after which he will record the hour and minute of the last tap [illegible]. As soon as the officer at Malta hears the first [illegible] of the officer at Syracuse, he will start his recording apparatus [illegible] and will commence making dots on the key [illegible] of his instrument in exact coincidence with the beats of his chronometer, [illegible] taking care to mark the beginning of each minute by omitting the [illegible] corresponding [illegible] seconds of his chronometer. This will be continued until the arrival of the second [illegible] from Syracuse, when he will cease tapping, and will record the hour and minute corresponding to the last tap which was omitted before the arrival of the [illegible]. He will then notify the officer at Syracuse whether or not the signals have been properly received. If they were not, they will be repeated; if they have been, the officer at Syracuse will telegraph to the officer at Malta the hour and minute corresponding to the last tap.

The taps on the Malta key [illegible] will make upon the Malta fillet a series of dots corresponding to the seconds of the Malta chronometer, thus producing a time scale in which the beginning of each minute will be designated by the omission of the dot corresponding to [illegible] seconds. Upon this time scale the taps on the Syracuse key [illegible] will record a series of dots corresponding to each [illegible] second of the Syracuse chronometer, and the beginning of each minute of that chronometer will be designated by two dots at an interval of one second. The hour and minute of each chronometer corresponding to the beginning of one of its minutes upon this time scale being known, it is evident that a very accurate comparison of the two chronometers will be obtained by simply reading off the scale.*

As soon as the officer at Malta has been notified of the hour and minute corresponding to the last signal sent from Syracuse, he will ask the officer at Syracuse if he is ready to receive signals from Malta, and upon receiving an affirmative reply the operations described above will be repeated, except that this time the signals will be sent by the officer at Malta tapping upon his key *h*, and will be received upon the Syracuse register *c*, while the officer there is tapping seconds upon his key *g*.

The following are the numerical details of the work. Each line in the columns headed "Number of Signals" gives the number of signals read off from the fillet, the mean of which furnished the chronometer comparison recorded on the same line. The headings of the other columns will be sufficiently intelligible without explanation, if it is borne in mind that the notation employed is that given on page 70.

Comparison of Chronometers obtained by reading off the Syracuse Fillet.

Date.	No. of Signals.	Negus 1115 at Syracuse.		Negus 1228 at Malta.	$(T'_s - T'_m)$
1870.		h. m. s.		h. m. s.	h. m. s.
Dec. 13	47	0 30 55.78	−	0 33 0.00	−0 2 4.22
14	34	3 12 55.52	−	3 15 0.00	4.48
15	37	3 14 55.19	−	3 17 0.00	4.81
16	37	1 9 54.81	−	1 12 0.00	5.19

Comparison of Chronometers obtained by Reading off the Malta Fillet.

Date.	No. of Signals.	Negus 1115 at Syracuse.		Negus 1228 at Malta.	$(T_s - T_m)$
1870.		h. m. s.		h. m. s.	h. m. s.
Dec. 13	40	0 21 0.00	−	0 23 4.23	−0 2 4.23
14	33	3 17 0.00	−	3 19 4.43	4.43
15	30	3 25 0.00	−	3 27 4.76	4.76
16	38	1 3 0.00	−	1 5 5.24	5.24

* From a discussion of 164 signals, exchanged between Syracuse and Malta, Professor Hall finds that the probable error of a chronometer comparison made by means of a single signal is only ± 0.034 of a second.

The probable error of a chronometer comparison obtained from the mean of thirty signals is about $\pm 0^s.007$.

As the rates of the chronometers were small, I assume $\Delta T_e = \Delta T'_e$, and $\Delta T_w = \Delta T'_w$. By means of a simple interpolation the tables on pages 59 and 71 furnish the

Chronometer Corrections at the Time of the Exchange of Signals.

Date.	Negus 1115 at Syracuse.	Negus 1228 at Malta.	$(\Delta T_e - \Delta T_w)$
1870.	h. m. s.	h. m. s.	h. m. s.
Dec. 13	+1 2 43.20	+0 57 29.55	+0 5 13.65
14	43.95	28.52	15.43
15	44.41	28.70	15.71
16	44.70	29.25	15.45

Resulting Differences of Longitude and Wave Times.

Date.	$\frac{1}{2}(T'_e - T'_w)$	$\frac{1}{2}(T_e - T_w)$	$(\Delta T_e - \Delta T_w)$	$\Delta\lambda$	t
1870.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	s.
Dec. 13	−0 1 2.11	−0 1 2.12	+0 5 13.65	+0 3 9.42	+0.01
14	2.24	2.22	15.43	10.97	− .02
15	2.41	2.38	15.71	10.92	− .03
16	2.60	2.62	15.45	10.23	+ .02

The negative values of t probably indicate that that quantity is less than the personal equation of the observers in tapping. If we give half weight to the result of December 13, we get

$$\Delta\lambda = +0^h\ 3^m\ 10^s.52 \pm 0^s.21$$

But an application of Peirce's criterion shows that the result of December 13 should be rejected; and as the time observations at Malta on that day were made on one side of the meridian only, and in consequence may be affected by a considerable constant error, I have discarded it. The mean of the remaining three results is

$$\Delta\lambda = +0^h\ 3^m\ 10^s.71 \pm 0^s.16$$

which I adopt as the best value obtainable from our work.*

It would seem that time determined by means of sextants used in the manner described above must be free from all personality; but, in order to make sure of this point, I compared Professor Hall's chronometer corrections, given on page 71, with my own, given on page 59, by means of the chronometer comparisons given on page 60. In that way I found that the correction necessary to reduce Professor Hall's time to mine was, on December 17, $+0^s.1$; on December 18, $+0^s.1$; on December 19, $+0^s.8$; and on December 21, $+0^s.5$. These numbers might be taken as an indication of a personal equation; but, as they are less than the change in the difference between the results of the forenoon and afternoon observations on these very days, I prefer to consider them as accidental errors, and to assume that no real personal equation exists.

* If we assume Professor Hall's chronometer to have had a constant rate from December 14 to December 21, then each of the three corrections observed at Malta will furnish an equation of condition involving the correction at a given date, the rate, and the difference of longitude between Syracuse and Malta; and each of the four corrections observed at Syracuse will furnish an equation of condition involving the correction at the given date, and the rate. Solving these equations by the method of least squares, the chronometric difference of longitude will be found to be $0^h\ 3^m\ 10^s.23$.

Our final result for difference of longitude will therefore be

	h.	m.	s.
Stone Gun-Platform, Syracuse, east of Telegraph Office, Malta . . .	0	3	10.71
Spencer's Monument, west of Telegraph Office at Malta		+	0.615
Light on Maniace Castle, east of Stone Gun-Platform, Syracuse . . .		+	0.861
Light on Maniace Castle, Syracuse, east of Spencer's Monument, Malta .	0	3	$12.19 \pm 0^s.16$

The English Admiralty chart, dated December 10, 1869, gives, as the difference of longitude between these two points, $0° \, 47' \, 24'' = 0^h \, 3^m \, 9^s.6$, a value which is too small by $2^s.6 = 39''$.

Difference of Longitude between Malta and Gibraltar.

The observations at Malta were made by Professor Hall, as described above. Those at Gibraltar were made by Professor Newcomb, with a Gambey sextant of seven inches radius and a mercurial artificial horizon; and as he observed in three different localities, it is desirable, in the first place, to determine the reduction from each of these localities to some well-marked position. In order to accomplish this with as much accuracy as possible, I procured a copy of the English Admiralty chart of Gibraltar, dated July 27, 1869, the topography upon which is from the Ordnance plan of 1868, and the scale of which is 1.00 inch to 1031 feet. Upon this chart the Signal Tower and the Base of the New Mole were marked, and Professor Newcomb was kind enough to point out on it the exact location of the Telegraph Office and the approximate positions of the American Consul's House and of his station at Buena Vista. Then, by means of the ordinates given on page 9 of his report, I laid off the position of Buena Vista Station from the Signal Tower, from the Base of the New Mole, and from the Telegraph Office. To my surprise I obtained three different points, two of which fell in the sea. To unravel the difficulty, I laid down on a piece of tracing-paper the relative positions of the Telegraph Office, the American Consul's House, the Signal Tower, the Base of the New Mole, and Buena Vista Station, employing for that purpose the scale of the chart and Professor Newcomb's co-ordinates. Then superposing the tracing-paper on the chart in such a manner that the Signal Tower and the Base of the New Mole marked upon the former fell over the same points marked upon the latter, I found that all the other points marked on the paper also coincided with the corresponding points on the chart as accurately as could be expected when it was considered that the measurements of the ordinates were only made to the nearest hundred feet. Distributing the outstanding differences as evenly as possible among the several known stations, I transferred the positions of Buena Vista Station and the American Consul's House to the chart with all desirable accuracy by pricking them through from the tracing-paper. From the position of Buena Vista Station thus determined the ordinates of the other stations were measured on the chart, and the results are given in the columns X and Y of the following table; the axis of X being taken in the meridian, and that of Y in the prime vertical. The numbers in the columns r and A have been computed from those in the columns X and Y by means of the formulæ

$$r = 1031 \sqrt{X^2 + Y^2} \qquad \tan A = \frac{Y}{X}$$

r being the distance and A the azimuth from Buena Vista to any other station. The numbers in the columns r' and A' have been computed from Professor Newcomb's co-ordinates by means of the formulæ

$$r' = \sqrt{X'^2 + Y'^2} \qquad \tan A' = \frac{Y'}{X'}$$

Station.	Admiralty Chart.					Newcomb.			$A'-A$	
	X	Y	r	A		r'	A'			
	in.	in.	feet.	°	′	feet.	°	′	°	′
Telegraph Office	8.42 N.	2.12 W.	8950	165	51	8910	170	58	+ 5	7
American Consul's House .	0.63 N.	1.32 W.	6070	168	45	6950	173	23	+ 4	38
Signal Tower	5.60 N.	0.58 E.	5800	185	56	5710	191	9	+ 5	13
Flag-Staff at Landing-Place .	2.60 N.	1.80 W.	3200	145	10					
Base of New Mole	2.50 N.	2.08 W.	3350	140	14	3360	143	27	+ 3	13

A comparison of the distances in the columns r and r' shows that they are as nearly identical as could be expected, considering the rough nature of Professor Newcomb's measurements; but the azimuths in the columns A and A' differ from each other considerably, as shown in the column $A'-A$, and indicate an angle of about five degrees between the direction of the meridian employed by Professor Newcomb and that of the Admiralty chart. Adopting the meridian of the chart, I find the following reductions necessary in passing from the stations named to Buena Vista:

Station.	Reduction in Latitude.	Reduction in Longitude.
	′ ″	′ ″
Telegraph Office	− 1 25.8	− 0 26.7
American Consul's House .	− 1 7.6	− 0 16.6
Flag-Staff at Landing-Place .	− 0 26.5	− 0 22.6

The minus sign before a reduction in latitude, or longitude, indicates that the station to which it belongs is further north, or further west, than Buena Vista.

Professor Newcomb obtains from his observations the following results:*

Observations for Latitude.

Date.	Station.	Object.	No. of Altitudes.	Observed Latitude of Station.	Resulting Latitude of Buena Vista.
1870.				° ′ ″	° ′ ″
Dec. 15	Telegraph Office . . .	Sun . .	6	+ 36 8 25	+ 36 6 59.2
15	Telegraph Office . . .	Polaris .	5	8 25	59.2
20	Buena Vista Station . .	Sun . .	6	6 44	44.
26	American Consul's House	α Ceti . .	5	7 41	33.4
26	American Consul's House	Polaris .	6	8 12	64.4

Taking the means, I find

	°	′	″
From the Sun and α Ceti	+ 36	6	45.5
From Polaris			61.8

which seems to indicate that the observations are affected by a constant error amounting to $8''.1$. Correcting for this error, I obtain finally

$$\text{Latitude of Buena Vista Station} = +\,36^\circ\ 6'\ 53''.6 \pm 2''.8$$

* For the observations in detail see pages 17 to 21.

Chronometer T. S. & J. D. Negus, No. 1265, fast of Local Mean Time by Observation.

Date.		Station.	Object.	Side of Meridian.	Number of Altitudes.	Correction to Chronometer.
	d.					h. m. s.
Dec.	14.95	Telegraph Office, Gibraltar . . .	Sun	E.	4	−0 22 8.7
	15.15	Telegraph Office, Gibraltar . . .	Sun	W.	7	16.3
	15.25	Telegraph Office, Gibraltar . . .	α Lyræ . . .	W.	4	16.1
	15.40	Telegraph Office, Gibraltar . . .	Jupiter . . .	E.	7	16.9
	15.42	Telegraph Office, Gibraltar . . .	α Andromedæ .	W.	2	16.8
	16.32	Telegraph Office, Gibraltar . . .	α Lyræ . . .	W.	5	14.6
	20.11	Buena Vista Station, Gibraltar . .	Sun	W.	3	19.1
			Observed with Portable Transit.			
Dec.	20.34	Buena Vista Station, Gibraltar . .	8 stars			−0 22 20.84
	21.36	Buena Vista Station, Gibraltar . .	7 stars			21.22
	22.42	Buena Vista Station, Gibraltar . .	7 stars			21.70
	23.01	Buena Vista Station, Gibraltar . .	1 star			22.7

The reduction of a chronometer correction from the Telegraph Office to Buena Vista is $+1^s.78$.

The length of the submarine telegraph cable between Malta and Gibraltar is 1025 knots = 1389 statute miles = 2235 kilometers. It is worked by means of condensers, no battery current being allowed to enter the line. The instruments employed for the purposes of communication are Sir William Thomson's reflecting galvanometers. For information as to the method of sending and receiving the longitude signals reference may be made to page 24 of Professor Newcomb's report and page 41 of Professor Hall's report. The following are the numerical details of the work:

Comparison of Chronometers obtained from the Signals received at Malta.

Date.	Number of Signals.	Negus 1228 at Malta.	Negus 1265 at Gibraltar.	$(T_c - T_w)$
1870.		h. m. s.	h. m. s.	h. m. s.
Dec. 15	18	4 47 43.68 =	4 48 0.00	−0 0 16.32
16	21	23 34 43.05 =	23 35 0.00	16.95

Comparison of Chronometers obtained from the Signals received at Gibraltar.

Date.	Number of Signals.	Negus 1228 at Malta.	Negus 1265 at Gibraltar.	$(T'_c - T'_w)$
1870.		h. m. s.	h. m. s.	h. m. s.
Dec. 15	18	4 55 0.00 =	4 55 17.34	−0 0 17.34
16	17	23 42 0.00 =	23 42 18.13	18.13

The probable error of a chronometer comparison obtained from the mean of eighteen signals is about $\pm 0^s.01$.

As the rates of the chronometers were small, I assume $\Delta T_e = \Delta T'_e$, and $\Delta T_w = \Delta T'_w$. The corrections of the chronometers at the times of exchanging signals have been obtained as follows: A simple interpolation among the numbers contained in the table on page 71 gives, for the correction to the Malta chronometer on December 15, $+ 0^h\ 57^m\ 28^s.72$. By means of the known difference of longitude, and the telegraphic comparison of chronometers, the Syracuse observations give, for the correction of the Malta chronometer on the same date, $+ 0^h\ 57^m\ 28^s.91$. The mean of these two results is $+ 0^h\ 57^m\ 28^s.82$, which I adopt. In the same way, on December 16 I find the correction of the Malta chronometer to be, from the Malta observations, $+ 0^h\ 57^m\ 29^s.22$, and from the Syracuse observations, $+ 0^h\ 57^m\ 28^s.78$. The mean is $+ 0^h\ 57^m\ 29^s.00$, which I adopt. The mean of Professor Newcomb's observations at Gibraltar, on December 15, gives, for the correction of his chronometer at $6^h\ 50^m$ p. m. on that day, $- 0^h\ 22^m\ 16^s.52$. A comparison of this correction with that obtained on December 20 gives, for the rate of the chronometer, $-1^s.21$ per day, allowance having been made for the difference of longitude between the Telegraph Office and Buena Vista. The correction of this chronometer, when it indicated $4^h\ 51^m$ p. m. on December 15, was therefore $- 0^h\ 22^m\ 16^s.42$. On December 16, at $7^h\ 45^m$ p. m., the observations make the correction $- 0^h\ 22^m\ 14^s.6$, and, by interpolating between this result and that of the day before, the correction at $11^h\ 38^m$ a. m. becomes $- 0^h\ 22^m\ 15^s.2$. If, on the other hand, we carry forward the correction from December 15 by means of the rate given above, we get $- 0^h\ 22^m\ 17^s.37$. Collecting our results, we have the following table of

Chronometer Corrections at the Time of the Exchange of Signals.

Date.	Negus 1228 at Malta.	Negus 1265 at Gibraltar.	$(\Delta T_e - \Delta T_w)$
1870.	h. m. s.	h. m. s.	h. m. s.
Dec. 15	+0 57 28.82	−0 22 16.42	+1 19 45.24
16	29.00	15.2	44.2
16	29.00	17.4	46.4

Resulting Differences of Longitude and Wave Times.

Date.	$\frac{1}{2}(T_e - T_w)$	$\frac{1}{2}(T'_e - T'_w)$	$(\Delta T_e - \Delta T_w)$	$\Delta\lambda$	t
1870.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	s.
Dec. 15	−0 0 8.16	−0 0 8.67	+1 19 45.24	+1 19 28.41	+0.51
16	8.48	9.06	44.2	26.7	.58
16	8.48	9.06	46.4	28.9	

On December 13, 14, 15, and 16, Negus 1115 was compared with two other chronometers at Syracuse, and, by means of the telegraph, with the Malta chronometer also. These comparisons show, beyond all question, that the latter instrument was running regularly, and, from an interval of seven days, Professor Hall's observations give it a daily gaining rate of $0^s.09$, but my own observations make the rate zero. The telegraphic comparisons of this instrument with the Gibraltar chronometer, on December 15 and 16, show, that the latter was certainly gaining not less than $1^s.00$ per day, while Professor Newcomb's time determinations on these days give it a losing rate of $1^s.89$. It therefore follows that at least one of the time determinations must be affected by a large error. That on December 15 depends upon observations of four different objects, three of them being to the west, and one to the east, of the meridian, and all giving nearly the same chronometer correction; while that on December 16 depends upon a single set of five altitudes of α Lyræ. Under the circumstances there cannot be the least hesitation in rejecting the latter, and with it the resulting value of $\Delta\lambda$, which is $+1^h\ 19^m\ 26^s.7$. From the method employed in arriving at the other value of the Gibraltar chronometer correction on the same day, it is evident that the resulting $\Delta\lambda$ depends almost wholly on the time determination of the 15th, and I therefore reject it also, and adopt the first value given in the table above, namely, $\Delta\lambda = +1^h\ 19^m\ 28^s.41$.

The observations for time having been made with sextants, used in such a manner as to eliminate all

constant errors, I assume that they are free from personal equation. The probable errors of the chronometer corrections, on December 15, are as follows: At Malta $\pm$ 0ˢ.07, derived from the discrepancies between the adopted correction and the corrections given, respectively, by Professor Hall's observations and my own. At Gibraltar $\pm$ 0ˢ.13, derived from the discrepancies between the individual corrections and the mean of the whole. The probable error of the telegraphic comparison of chronometers is $\pm$ 0ˢ.01. Hence the probable error of $\Delta\lambda$ is $\pm$ 0ˢ.15.

Our final result for difference of longitude will therefore be:

	h	m	s
Telegraph Office, Malta, east of Telegraph Office, Gibraltar	1	19	28.41
Spencer's Monument, west of Telegraph Office, Malta		—	0.615
Flag-Staff at Landing-Place, east of Telegraph Office, Gibraltar . .		—	0.271
Spencer's Monument, Malta, east of Flag-Staff, Gibraltar	1	19	27.52 $\pm$ 0ˢ.15

X.—GEOGRAPHICAL POSITIONS DETERMINED BY THE UNITED STATES NAVAL OBSERVATORY PARTIES.

Collecting our results, and rejecting superfluous figures, we have the following

Table of Geographical Positions.

[North Latitudes and West Longitudes are taken as positive.]

Station.	Latitude.			Longitude in Arc from Greenwich.			Longitude in Time from Greenwich.			Longitude in Time from Washington.		
	°	′	″	°	′	″	h.	m.	s.	h.	m.	s.
Flag-Staff at Landing-Place, Gibraltar .	+ 36	7	20	+ 5	20	45	+ 0	21	23.0	− 4	46	49.0
Buena Vista Station, Gibraltar	36	6	54	+ 5	20	22	+ 0	21	21.5	4	46	50.5
Spencer's Monument, Malta	35	52	59	− 14	31	8	− 0	58	4.5	6	6	16.5
Stone Gun-Platform, Syracuse	37	3	53	15	18	57	1	1	15.8	6	9	27.8
Prof. Harkness' Telescope, Syracuse. .	37	3	52	15	18	57	1	1	15.8	6	9	27.8
Prof. Eastman's Telescope, Syracuse. .	37	3	52	15	18	58	1	1	15.9	6	9	27.9
Mr. Brothers' Telescope, Syracuse . .	37	3	50	15	18	58	1	1	15.9	6	9	27.9
Light-House on Maniace Castle, Syracuse	+ 37	3	8	− 15	19	10	− 1	1	16.7	− 6	9	28.7

Owing to a break in the telegraph cable between Gibraltar and Lisbon, Professor Newcomb was unable to connect his station with Greenwich, and I have therefore made all our longitudes depend upon the position of the Flag-Staff, at the Landing-Place, in Gibraltar, which I have taken to be 0ʰ 21ᵐ 23ˢ.0 west of Greenwich.

In order to show precisely how much the positions given by our observations differ from those heretofore adopted, I append the following list, which is made up from the latest English Admiralty charts. The columns *dL* and *dM* contain respectively the corrections which must be applied to the latitudes and longitudes of the charts in order to reduce them to our own.

Station.	Latitude.			*dL*	Longitude.			*dM*	Date of Chart.
	°	′	″	″	°	′	″	″	
Flag-Staff at Landing-Place, Gibraltar . . .	+ 36	7	10	+ 10	+ 5	20	45	0	July 27, 1869
Spencer's Monument, Malta	35	53	0	− 1	− 14	31	0	− 8	Aug. 16, 1861
Light-House on Maniace Castle, Syracuse .	+ 37	3	0	+ 8	− 15	18	24	− 46	Dec. 10, 1869

XI.—MAGNETIC DECLINATION AT SYRACUSE.

In order to determine the magnetic declination, I made the following observations of the bearing of the Belvedere Tower, from the Stone Gun-Platform, with my prismatic compass, the card of which is divided to single degrees, and numbered from 0° to 360°; 0° corresponding to the magnetic south, and the numbers increasing toward the west. It has an index error of + 0°.6. The true bearing of the Belvedere Tower was N. 68° 23′ W. = 111°.6.

Date.	Time.	Magnetic Bearing of the Belvedere Tower.	Resulting Magnetic Declination.
1870.		°	°
Dec. 16	4.00 p. m.	124.0	12.4 west
17	12.30 p. m.	124.0	12.4 west
18	9.40 a. m.	124.0	12.4 west
21	8.10 a. m.	123.9	12.3 west

Taking the mean, we have

Observed magnetic declination	12° 22′ west.
Correction for index error of compass	— 36′
True magnetic declination	11° 46′ west.

The probable error of this result I estimate at ± 8′.

XII.—OBSERVATIONS ON THE DAY OF THE ECLIPSE.

Before describing the observations on the day of the eclipse, I must not forget to mention that, without even a hint from us that such a thing would be desirable, the Prefect most kindly directed the military commandant, Lieutenant Colonel Augusto Rossi, to furnish a sufficient number of troops to insure the maintenance of order and quiet in the neighborhood of our observing station on that occasion. For this purpose the bastion was guarded by a battalion of infantry from a little before noon till after the eclipse was over, and, although a great crowd of people gathered in the street opposite, we were enabled to make our observations without any interruption. We owe the Prefect and Lieutenant Colonel Rossi sincere thanks for their thoughtfulness in contributing to our success.

While at Malta I was so fortunate as to make the acquaintance of Captain G. L. Tupman, of the Royal Marine Artillery, who was at that time attached to the English iron-clad ship of war Prince Consort. Being an enthusiastic amateur astronomer, he became interested in our expedition and most generously volunteered to assist me in the spectroscopic observations, by directing the finder of my telescope to the various parts of the corona which it might be desirable to examine. He arrived in Syracuse on the morning of Wednesday, December 21, and rendered most efficient service, not only during the eclipse itself, but also in much of the preliminary and subsequent work. His letter describing his observations forms Addendum D to this report, and it affords me great pleasure to place on record an acknowledgment of the obligations which the expedition owes to him.

For eight days after our arrival in Sicily the weather was superb; but on December 20 a change took place, the barometer began to fall, the wind began to rise, and, although at times the heavens were perfectly clear, still for the most part they were either completely overcast or else flecked with drifting clouds, and this state of affairs continued long after we left Syracuse. However, at the beginning of the eclipse the sky in the neighborhood of the sun was perfectly clear, and I observed the first contact with my three-inch telescope, armed with a Huygenian eye-piece magnifying 65½ diameters, at $11^h\ 35^m\ 27^s.5$ by the face of the chronometer Negus 1115. As the eclipse advanced I looked very carefully for the bright line which was shown in such a marked manner along the edge of the moon's limb in the photographs taken by Dr. Curtis, at Des Moines, in August, 1869, but, although I used both red and neutral tint shade glasses, and the definition in the telescope was excellent, I could not see any trace of it till $12^h\ 8^m$, when I fancied I saw a very faint and narrow bright line, but I am far from being certain that such a line really existed. In fact, I am inclined to think it was only the effect of contrast between the bright sun and the dark moon.

With the assistance of Captain Tupman, about $12^h\ 20^m$ I attached the spectroscope to the telescope, applied the necessary counterpoises, placed the slit so that it was inclined from a vertical circle about ten or fifteen degrees toward the north, and adjusted the needle in the finder so that when its point fell upon a horn of the solar crescent the image of that horn fell accurately within the jaws of the slit. A quarter of an hour before totality a dense cloud came over the sun and hid it entirely. The wind was blowing half a gale, and although my telescope, with its solid substantial mounting, was under the lee of the parapet of the bastion, it was far from being so steady as was desirable. When I tried to light my lanterns I found it was impossible, even in the most sheltered place, and I was obliged to take them into the store-house and light them there. In carrying them back to the telescope one was blown out, but by crouching down behind the parapet and sheltering it with our bodies, Captain Tupman and I succeeded in lighting it again, after which I attached it to the spectroscope to illuminate the micrometer scale. It was now within less than five minutes of totality, and fortunately the cloud covering the sun was fast becoming thinner. Presently a slender crescent, which was all that remained of the solar disk, became visible, dwindled rapidly away, and at $1^h\ 0^m\ 11.^s0$ I observed the commencement of totality with my naked eye. The cloud was sufficiently transparent to allow the corona to be seen through it, but, of course, much diminished both in extent and brilliancy, and I do not think it was more than half or two-thirds as extensive as that which I witnessed at Des Moines in August, 1869. On that occasion it had a well-marked trapezoidal form, but this time it seemed to me to be nearly circular; however, my view of it was limited to a mere glance at the commencement of totality, and it may have appeared differently afterward. The general illumination of the atmosphere was considerable; in fact, it was not really dark, for, in addition to the outlines of objects, the details were also visible to a considerable extent.

I spent the first ten or fifteen seconds of the totality in examining the corona with an Arago polariscope. This instrument consists of a plate of selenite and a double-image prism, placed almost in contact with each other, and mounted in a brass cell, 0.43 of an inch thick, for the purpose of slipping on to an eye-piece, so that it may be used for telescopic observation. The eye-piece contains a diaphragm of such diameter that when it is seen through the polariscope two circular fields of view appear, tangent to each other; and if polarized light is present these fields of view are of complementary colors. When the cell is removed from the eye-piece its field of view has no longer any well-defined boundary, and if a beam of polarized light is then examined with it the effect of the prism will be to displace one portion of the beam upon another, and no complementary colors can appear except at the very edge of the field. Now, bearing in mind that the separating angle of the prism is $2°\ 31'$, let us apply this to the case of the eclipse. Looking at the corona through the polariscope, two images of it will be seen well separated from each other, and everywhere else one portion of the sky will be displaced upon another portion $2°\ 31'$ distant. Under these circumstances, no matter whether the sky is polarized or not, it can exhibit only its natural color, unless, indeed, the polarization varies so rapidly that its difference at points $2°\ 31'$ apart is sensible in the instrument. If the corona is polarized in the same plane, and to precisely the same extent, as the surrounding sky, the two images of it will also appear of their natural color; but if it is either more or less polarized than the surrounding sky these images will be of complementary tints, and the arrangement of the tints will show whether the polarization is radial or confined to a single plane. In order to discriminate between the cases where the corona is polarized to an extent different from the surrounding sky, or not polarized at all, it will be necessary to examine it with the same polariscope, provided with a diaphragm so arranged as to exhibit two fields of view tangent to each other. Then, if the corona is polarized, the two images will be of complementary tints, while if it is not polarized, they will be or their natural color. The experiments I tried were therefore as follows: First I employed the polariscope provided with a diaphragm, and I saw that in each field the sky and the corona were of the same tint, but in the two fields these tints were complementary to each other. Next I employed the polariscope without the diaphragm, and I then saw the sky of its natural color, and the two images of the corona also of their natural color. Clearly, the inference to be drawn from these observations is that, so far as the instrument was capable of determining, the light from the sky and that from the corona were polarized to the same extent; and knowing that the polarization of the sky is produced in our own atmosphere,* I infer that that of the corona had the same origin, and there-

* It may be objected that under the circumstances of a total eclipse we do not know that the polarization of the sky is produced in our atmosphere, because the light of the sky will then be principally due to the corona, and if the light of the latter is polarized that of the former must also be so. To this I reply that the quantitative observations made at Syracuse by Mr. G. Griffith, of the English Expedition, show that the amount of polarization increased from the moon's center outward; a fact which can only be accounted for by supposing the polarization to be effected in our atmosphere.

fore that when the light was emitted from the corona it was not polarized at all. As the tints were faint it was difficult to determine the plane or planes of polarization, and I could not spare time for the attempt.

Dropping the polariscope, I sprang to the spectroscope, and Captain Tupman directed it to the corona. I at once saw a green line, but the wind had blown out the lantern which illuminated the micrometer scale, and, in order to determine the position of the line, I seized my second lantern, which was standing in a sheltered place, held it to the spectroscope, glanced in, saw that the reading was about the same as at Des Moines in 1869, and before I could determine it accurately the wind blew out this lantern also, and I was deprived of all means of making exact measures. However, there cannot be the slightest doubt that the line in question was the now famous 1474, whose wave length is 531.6 millionths of a millimeter. Captain Tupman then directed the spectroscope to many different parts of the corona, and wherever the light was sufficiently bright to show anything I saw the same green line. It is difficult to say precisely how far I traced it from the sun, but certainly to a distance not less than from ten to fifteen minutes. Once I saw two other fainter green lines, of a less degree of refrangibility, which I am pretty confident also belonged to the corona. In addition to these, I several times saw a complete hydrogen spectrum, and on each occasion, supposing it to be due to a prominence, I taxed Captain Tupman with having the needle point of the finder near one of them. Once or twice he admitted that such was the case, but in one or two other instances he denied it. Feeling certain that the lines were produced by prominences, I paid little attention to the circumstance at the time; but on talking over the subject with the Captain afterward, he assured me that on at least one occasion I accused him of having the pointer near prominences when such was not the case. This puzzled me considerably, but after a little reflection I hit upon what I think is the true explanation. The slit of the spectroscope had a length of 0.20 of an inch, which, with the telescope employed, would give a field of view 15′ 46″ high. Hence, when the slit was radial to the sun, one end of it might easily be upon a prominence when the needle point in the finder was eight minutes distant from it. During the last few seconds of totality the thin cloud covering the sun became nearly dissipated, and the faint, continuous spectrum of the corona became visible, but before there was time to examine it the totality was over. Notwithstanding the evidence of the chronometer, I could scarcely believe it had lasted one hundred and two seconds. It seemed to me but a moment, and I felt far from satisfied with what I had accomplished. The high wind and the thin cloud over the sun placed me at a great disadvantage, and prevented me from doing much that would have been easily within my grasp under more favorable circumstances.

Five minutes after the totality was over the sky in the neighborhood of the sun became perfectly clear and remained so till the last contact, which I observed at $2^h\ 19^m\ 0^s.0$. It will be noticed that this time is considerably earlier than that given by Professors Hall and Eastman, but, unless I made a mistake of ten seconds in reading the chronometer, I am unable to explain the cause of the difference. The wind had gone down, so that my telescope was as steady as the ground on which it stood; the definition was admirable, the power 65½, and I left the eye-piece under the impression that I had recorded the contact perhaps a little too late.

I believe the following table contains all the times of contact observed at Syracuse. The different columns explain themselves. The adopted local mean time depends upon the correction derived from my own observations for the chronometer Negus 1115. Professor Hall's observations to determine the error of the chronometer Negus 1228 would make all these times $0^s.5$ earlier.

Times of Contact between the Limbs of the Sun and Moon, observed at Syracuse, Sicily, during the Total Solar Eclipse of December 22, 1870.

Observer.	Chronometer.	Contact.	Observed Time.	Local Mean Time.
			h. m. s.	h. m. s.
Eastman. . . .	Negus 1340	First .	11 39 12.	0 38 18.2
Griffith	Negus 1256	First .	37 30.	38 35.4
Hall	Negus 1228	First .	37 35.	38 13.5
Harkness . . .	Negus 1115	First .	35 27.5	38 13.2
Tupman. . . .	Negus 1115	First .	35 30.	38 15.7
Eastman. . . .	Negus 1340	Second.	1 3 51.0	2 2 57.1
Griffith	Negus 1256	Second.	1 51.	2 56.4
Hall	Negus 1228	Second.	2 17.5	2 56.0
Harkness . . .	Negus 1115	Second.	0 11.	2 56.7
Tupman. . . .	Negus 1115	Second.	0 9.5	2 55.2
Eastman. . . .	Negus 1340	Third .	1 5 32.5	2 4 38.6
Griffith	Negus 1256	Third .	3 37.	4 42.4
Hall	Negus 1228	Third .	4 0.	4 38.5
Tupman. . . .	Negus 1115	Third .	1 55.	4 40.7
Eastman. . . .	Negus 1340	Fourth.	2 22 53.5	3 21 59.4
Griffith	Negus 1256	Fourth.	20 34.	21 39.4
Hall	Negus 1228	Fourth.	21 20.5	21 59.0
Harkness . . .	Negus 1115	Fourth.	19 0.	21 45.7*

* Probably there was a mistake of 10^s in reading the chronometer, and this should be $3^h\ 21^m\ 55^s.7$.

Having thus stated the facts, it only remains to consider what light they throw upon solar physics and the phenomena exhibited during eclipses. This we will now proceed to do.

Origin of the Bright Line seen along the Projection of the Moon's Limb upon the Solar Disk in Photographs of Eclipses.—This line seems to have been observed upon all photographs of solar eclipses hitherto taken, and its cause has been the subject of much discussion, in which such eminent men as Mr. Airy, Professor Challis, and Mr. De La Rue have participated. After the eclipse of August, 1869, Professor Henry Morton examined the question, and made some experiments which showed pretty conclusively that the phenomenon is a chemical effect produced in developing the photograph;* while, on the other hand, Dr. Edward Curtis, in his report on the same eclipse,† described other experiments tending to show that it is due to diffraction, and this view he further supported by a note from Dr. F. A. P. Barnard, in which an attempt is made to show that such a bright line was to be expected as a consequence of the undulatory theory of light. Finally, in March, 1870, Professor Edward C. Pickering made a critical examination of Dr. Barnard's theory, and showed most conclusively from Fresnel's equations that diffraction was not capable of producing the effect which had been attributed to it.‡ Under these circumstances the inquiry naturally arose whether or not the line was visible to the eye during the progress of an eclipse. Here again the evidence was contradictory, Professor Stephen Alexander affirming that he saw it in 1831, and again at Labrador in July, 1860,§ while Professor Smith was unable to detect it in August, 1869. I therefore made it an object of special attention during the eclipse of last December, and, as already stated, I failed to find it. On the whole, I think we are entitled to conclude that the line has no real existence during an eclipse, and that Professor Morton's explanation of its presence on the photographs is the true one.

Is the Light of the Corona Polarized prior to entering the Earth's Atmosphere?—As already stated, my observations tend to answer this question in the negative; but the evidence afforded by other observers is so conflicting that the matter cannot be regarded as settled, and must be an object of further investigation in future eclipses.

Spectrum of the Corona.—All parts of the corona which are sufficiently near the sun give a faint but abso-

* Journal of the Franklin Institute, December, 1869, Vol. 58, p. 373.
† Washington Observations for 1867, Appendix II, pp. 135 to 141.
‡ Journal of the Franklin Institute, April, 1870, Vol. 59, p. 264.
§ United States Coast Survey Report for 1860, p. 241.

lutely continuous spectrum, crossed by a single bright line, whose wave length is 531.6 millionths of a millimeter; and as the spectroscope is moved outward from the sun the light gradually vanishes, the continuous spectrum disappearing first, and afterward the bright line. Judging from Professor Young's observations in August, 1869, and from Father Denza's and my own in December, 1870, I feel pretty certain that some parts of the corona give in addition two other bright lines in the green, which are fainter and less refrangible than that whose wave length is 531.6. The origin of the faint continuous spectrum I attribute mostly to the presence of a little comparatively cool hydrogen in those parts of the corona nearest the sun, but it may also be partially due to the substance which gives the bright line. This latter substance I am inclined to think is most probably incandescent vapor of iron, but it would not be surprising if it turned out to be a new element.

Physical Constitution of the Corona.—That the corona is partially self-luminous, emitting light whose wave length is 531.6, is now universally conceded; but at least one high authority seems to hold the opinion that the self-luminous portion does not extend more than from two to six minutes above the surface of the sun, and that all parts of the corona outside of that limit are produced by means of reflection taking place at some point not definitely specified. Let us examine this theory. If there is any reflection in the case it must happen in one of three places, namely: 1. In the earth's atmosphere, under which term I include a space extending not more than one hundred miles from the earth's surface; 2. Between the upper limit of the earth's atmosphere and the moon; or 3. In the neighborhood of the sun.

Before considering where the reflection takes place, it will be well to comprehend clearly the circumstances under which reflection is possible. Fortunately, on this point the experiments of Professor Tyndall are perfectly decisive. By passing a powerfully condensed beam of electric light through his experimental tubes he found that no matter whether they were filled with air, gas, or vapor, so long as they contained neither dust, motes, nor other solid or liquid particles, they scattered no light, and it was only when such particles were produced within them that the presence of the electric beam became sensible.* We are therefore certain that air, and many other gases and vapors—probably all matter in the gaseous state—is absolutely incapable of reflecting any light whatever. Thus the theory that twilight is partly due to the reflection of the sun's rays by the atmosphere falls to the ground, and we learn that the only reflecting agents are impalpable dust and liquid particles. Hence, the duration of twilight gives us a measure, not of the height of the earth's atmosphere, but of the height to which dust and liquid particles extend in that atmosphere. We shall have occasion to apply this principle presently.

The heat of the oxy-hydrogen flame is sufficient to volatilize almost all known substances, but it will not suffice to render any gas incandescent. For that purpose the electric spark must be employed. We are therefore certain that the heat required to produce a gaseous spectrum is far greater than that required to volatilize any of the elements; and as the spectroscope shows that that part of the corona universally admitted to be self-luminous is composed of incandescent gas, we are entitled to conclude, with a degree of probability amounting almost to certainty, that no solid or liquid matter can exist in its neighborhood. But it has been already shown that gaseous matter is incapable of reflecting light, and it therefore follows that no part of the corona can be due to reflection taking place at or near the sun. This view is also supported by the fact that what little polarization is found in the light of the corona seems to be produced in the earth's atmosphere.† Furthermore, as the light of the photosphere exceeds that of the chromosphere at least 500,000 times, if any reflection takes place between the sun and a point, say, one hundred miles above the earth's surface, we should expect the light so reflected to be that of the photosphere, but no photospheric light has ever been detected in any part of the corona. Professor Young has indeed said that the continuous spectrum of the corona is partly due to such light, and has even given reasons to account for the absence of Fraunhofer's lines in it;‡ but nearly two years ago I suggested that this continuous spectrum was probably due to cool hydrogen,§ and lately Mr. Lockyer has succeeded in showing experimentally that this gas when at a comparatively low temperature does yield a continuous spectrum, together with the bright line F, and, if I do not misunderstand him, he also is now of the opinion that it is the cause of the continuous spectrum of the corona.‖ On the whole, it seems certain that there is no reflection anywhere between the surface of the sun and the moon's orbit.

* See Tyndall's Fragments of Science, pp. 246 and 306.

† It will be observed that no matter whether the light of the corona is polarized near the sun or in the earth's atmosphere, we should expect the polarization to be radial.

‡ American Journal of Science, [3,] Vol. I, p. 311, and Vol. II, p. 53.

§ Washington Observations for 1867, Appendix II, foot-note on page 65.

‖ Nature, Vol. IV, p. 250.

The whole tendency of modern discovery is to show that the earth's atmosphere has a definite upper limit; but, in order to make as strong a case as possible for the theory that part of the corona is produced by reflection taking place between the moon and the earth, we will suppose that it extends to, or beyond, the moon's orbit. Then we may compute the density of the atmosphere which the moon would be capable of gathering about itself as follows: Taking the diameter of the earth to be 7926 miles, that of the moon to be 3963 miles, and the moon's mass to be 0.0114 that of the earth, it can be shown that at an elevation of 6120 miles above the earth's surface terrestrial gravity will be reduced to an equality with that existing at the moon's surface. If we assume that the laws which govern the expansion of gases near the earth's surface still hold at that altitude, Laplace's barometrical formula will give for the atmospheric pressure there $\frac{6}{10^{210}}$ of an inch of mercury,* which will also be the pressure at the moon's surface.

If we let

N = number of particles in a unit of volume of any gas;
M = mass of each particle;
v = velocity of each particle;

then it can be shown from the mechanical theory of gases that, at the same pressure and temperature, both N and Mv^2 are constant for all gases.† It is well known that the luminiferous ether behaves in many respects more like a solid than a gas, and that the vibrations of sound are longitudinal, while those of light are transversal; but, for the sake of getting a rough approximation to the *order* of density of the luminiferous ether, we will assume that this ether is a gas, and that the velocity of light in it is the same function of its v that the velocity of sound in oxygen and hydrogen gas is of their v's. The best authorities give, for the specific gravity of oxygen, 1.1056, and for the velocity of sound in it, 317.0 meters per second; for the specific gravity of hydrogen, 0.0693, and for the velocity of sound in it, 1269.1 meters per second. These numbers give, for oxygen, $\log Mv^2 = 5.0456$; and for hydrogen, $\log Mv^2 = 5.0477$. The mean is, $\log Mv^2 = 5.0466$, which I adopt.‡ In order to avoid all questions of pressure and temperature, I take as the velocity of light the value found by M. Foucault, from experiments made in the Paris Observatory, namely 298,000,000 meters per second.§ Taking air as unity, this gives for the specific gravity of the luminiferous ether $\frac{125}{10^{14}}$; and as air at the earth's surface supports a column of mercury 30 inches high, it will follow that under the same circumstances the ether would suppor a column $\frac{376}{10^{13}}$ inches high. Taking into consideration the fact that the velocity of light found by Foucault in the rooms of the Paris Observatory scarcely differs from that found in space by means of the eclipses of Jupiter's satellites, I think we must admit that the density of the luminiferous ether is not affected by gravity, and that it will probably be the same at the moon's surface as at the earth's surface. Now, comparing the density just found for this ether with that computed for the atmosphere at the moon's surface, it will be seen that the former is 62×10^{197} times greater than the latter!

No one can be more sensible than myself of the very great uncertainty to which these figures are liable; but after making an enormous allowance for the effect of errors, they would still suffice to prove that the moon is not capable of retaining an atmosphere such as ours, even if she had once been provided with it, and that beyond a comparatively short distance from the earth's surface no matter possessing the power of reflecting light can possibly exist, unless moving with a velocity comparable with that of the planets.

We naturally come next to the consideration of Oudeman's theory, which he states thus: "Both the corona and its beams have the same origin as the zodiacal light."‖ As the origin of the zodiacal light is one of the greatest enigmas of astronomy, this explanation would be somewhat difficult to understand, were

* As some copies of this report will fall into the hands of persons whose scientific attainments are but moderate, and to whom the notation $\frac{6}{10^{210}}$ may not be familiar, perhaps it will be well to write this quantity out as a decimal fraction. It will then stand thus: 0.00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000-
000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000-
0006.

† Illustrations of the Dynamical Theory of Gases, by Professor J. C. Maxwell. L. E. & D. Phil. Mag., 1860, Vol. XIX, p. 30.

‡ Strictly, these numbers are not the logarithms of Mv^2, but of Mv^2 multiplied by an unknown constant.

§ Comptes Rendus, Nov., 1862, p. 796.

‖ Nature, Vol. III, p. 26.

it not that in another part of his article he attributes its production to "particles which float in the ether" between the earth's atmosphere and the sun, and thus reflect the solar light to us. As already shown, the duration of twilight furnishes an accurate measure of the height above the surface of the earth at which particles capable of reflecting the sunbeams can float, and the result obtained in this way is usually considered to be 45 miles. I am not aware that any observations have ever been made which give a result so great as 100 miles. Employing Laplace's barometrical formula as before, and expressing the density of the air in terms of the height of the column of mercury which it can sustain, I find the density at 45 miles elevation to be 0.0038 of an inch, and at 100 miles $\frac{87}{10^{9}}$, or 0.000000087, of an inch. As the least of these densities is more than 2300 times greater than that found above for the luminiferous ether, it does not seem possible that particles of any known substance can float in it. If any particles exist they must therefore be moving in orbits about either the moon, the earth, or the sun—in other words, they must be meteoroids. The richest stream of these bodies of which we have any knowledge is that through which the earth passes annually on or about November 13, but the most condensed portion of that stream is only encountered once in thirty-three years. Our last encounter with it was on the night of November 13–14, 1867, and on that occasion, during the thickest of the shower, the officers on duty at this Observatory counted the falling meteors at the rate of 3000 per hour; from which Professor Newcomb found that on an average there was one meteoroid in 900,000 cubic miles of space*. Clearly, even if the stream were increased in density a hundred-fold, the sun-light which it would be capable of reflecting could not produce any continuous illumination however faint. Thus, then, all the facts within our knowledge seem to point to the conclusion that no reflecting substance which can have any influence in the production of the corona exists between the earth's atmosphere and the sun.

Now let us examine the phenomena which are relied upon to prove that the origin of some part of the corona is due to reflection taking place in the earth's atmosphere. These phenomena may be classed as follows: 1. Drawings of the corona of one and the same eclipse made by persons at different places differ from each other greatly. 2. During the eclipse of last December, Professor Peirce, stationed two miles from Catania, Sicily, saw the outer corona tinged rosy-red over the prominences—a place where no intensely heated hydrogen could possibly exist.† 3. During the same eclipse, Professor Young, stationed at Xeres, in Spain, saw the line C, 6′ or 7′ from the sun, far above any possible hydrogen atmosphere;‡ Mr. Perry, also in Spain, saw a hydrogen spectrum 8′ away from the sun;§ and some observer in Spain,‖ about whom I have not been able to get any definite information, seems to have seen a hydrogen spectrum upon the face of the dark moon itself.

The light here referred to as giving rise to some part of the corona by reflection in the earth's atmosphere, I understand to be that of the chromosphere and corona itself. The theory that direct sun-light might be so reflected was discussed in my report on the eclipse of August, 1869,¶ and it is not necessary to refer to it again at present, more especially as I believe it is now universally admitted that such a theory is entirely untenable.

In reply to the first class of evidence adduced above to prove reflection, I would urge that no reliable deductions can be obtained from the differences existing between drawings made at places some distance apart, because it is well known that fully as great differences are seen in drawings made by persons stationed within a few feet of each other. An excellent illustration of this was furnished during the eclipse of last December. A fleet of one Italian and five English vessels of war were at Aci Reale, on the coast of Sicily, trying to save the English dispatch-vessel Psyche, and many drawings of the corona were made by the officers of these vessels; but, judging from the published account, no two of them were alike. In fact, two sketches made on the deck of the same ship, the Lord Warden, were so different that it could not have been supposed they were intended to represent the same object.** These differences probably arose partly from want of artistic skill, and still more from the bewildering effect of the strange and exciting phenomena of a total eclipse witnessed, perhaps, for the first time. I have seen so many instances of amateurs making

* United States Naval Observatory Reports on the November Meteors of 1867, p. 11.
† Nature, Vol. III, p. 222.
‡ Nature, Vol. III, p. 261.
§ Nature, Vol. III, p. 223.
‖ Quoted by Mr. Lockyer in Nature, Vol. III, p. 223.
¶ Washington Observations for 1867, Appendix II, p. 64. See also Proctor's Work on the Sun, p. 357.
** Nature, Vol. III, pp, 222 and 223.

magnificent sketches of celestial phenomena, which could not possibly have existed, that I confess I have little confidence in any delineations of the corona not made by trained observers who were at the same time competent draughtsmen. Furthermore, it is a matter of common experience that whenever a bright object is seen on a dark ground, that object will appear to be surrounded by a greater or less number of very distinct rays. Yet no one imagines these rays to be real. They are purely subjective, and can be made to disappear from the most dazzling object by looking at it through a dark glass, or from a moderately bright object by viewing it through a telescope of low power. That the corona exhibits real rays cannot be doubted, because they have been photographed; but, as it is a bright object on a dark ground, when viewed by the naked eye it will surely be surrounded by some spurious ones also, and therefore no confidence can be placed in the reality of the existence of any *faint* rays which have not been seen by means of a telescope or opera-glass. To recapitulate, the conditions necessary for the production of a trustworthy drawing of the corona are, that the person making it shall be a trained observer and competent draughtsman, and that no details shall be recorded which are not visible through an opera-glass.

Mr. Lockyer, in two very able papers relative to the eclipse of last December, has said that although Mr. Brothers' photographs taken at Syracuse show such vast rifts in the corona, none of these rifts were *seen* by any of our party; and to this statement he appears to attach considerable importance.* I regret to say that he is in error as to the facts. The great rift was seen by Professor Hall, and is mentioned in his report.†

As to the second and third classes ot evidence adduced above to prove that part of the corona is due to reflection taking place in the earth's atmosphere, I have only to say that they apply solely to the eclipse of last December, which happened at a time when the heavens were thick with haze and clouds of all kinds, and no one has ever for an instant thought of denying that light passing through such an atmosphere must be more or less reflected. Manifestly these proofs have no application to the case of a clear and transparent sky, and there is not the slightest reason to suppose that the aspect of the corona seen in such a sky would be any more altered by it than that of a nebula, or the moon, seen under the same circumstances.

In view of the evidence which has been discussed, it seems safe to conclude that when the sky is perfectly clear there is nothing between the eye of the observer and the solar surface which can appreciably alter either the appearance or extent of the corona; and under such circumstances, anything seen in it by the aid of a properly adjusted telescope may be confidently received as representing phenomena occurring at the sun; but if the observations are made with the naked eye the real phenomena will almost certainly be more or less complicated by subjective appearances depending upon irradiation.

From the time of Dr. Wyberd in 1652, down to the present moment, there have not been wanting persons who say that the corona exhibits a rotary motion, but, as these statements are expressly contradicted by nearly all observers of known skill, it is not necessary to consider them further here. There still remains another class of phenomena which cannot be dismissed so summarily, because their existence has been affirmed by astronomers of the very highest reputation. I allude to variations in the brightness of the corona, and to rays, beams, or rifts in it. Otto Struve, observing at Lipesk in 1842, found the corona so bright that the naked eye could scarcely endure it. Mr. Airy has been fortunate enough to witness several total eclipses, and he testifies that the corona was much brighter in some of them than in others. The experience of the officers belonging to this Observatory is the same; the corona appeared much brighter in August, 1869, than in December, 1870. The existence of rays, streamers, and rifts in it is a matter of common notoriety. How are these appearances to be explained? Do we know of any other similar phenomena depending upon ascertained causes? I think we do. The sun is surrounded by a red hydrogen atmosphere, which varies in depth, just as the corona does. The outline of this atmosphere is broken by vast protuberances, corresponding to the rays, or streamers, of the corona. These protuberances vary in position, extent, and number, just as the rays or streamers do. And finally, these proturberances are sometimes brighter, sometimes fainter, depending upon the temperature of the hydrogen composing them, just as the rays of the corona vary in brightness. The analogy is complete, and, if we assume that the luminous gas composing the corona is ejected from the sun in the same manner as the red prominences, all the observed facts will be accounted for; even to such an extreme case as that exhibited in the picture made by Mr. Gilman at Sioux City, Iowa, in August, 1869‡—a picture, by the way, of whose accuracy I am convinced. Moist steam issuing

* Nature, Vol. III, p. 223, and Vol. IV, p. 232.
† See page 29 of these reports.
‡ Washington Observations for 1867, Appendix II, plate 12.

from a boiler at the very moderate pressure of fifty pounds per square inch develops torrents of electricity. The best information we possess indicates that the hydrogen of the red prominences is belched forth with a velocity of about one hundred and twenty miles per second, and it does not seem unreasonable to suppose that it may carry with it a little spray. If it does, then, judging from analogy, the friction of this spray against the mouth of the crater from which it is escaping will probably generate electricity in quantities of which we can have simply no conception, and it may very likely play some part in the production of the long streamers of the corona. In conclusion, the theory which I propose may be stated as follows:

When seen in a clear sky, the corona is a purely solar phenomenon, produced by a vast body of self-luminous gas—not improbably incandescent vapor of iron—which envelopes the sun and is erupted from it in the same manner as the red prominences.

Very respectfully,

WM. HARKNESS,
Professor of Mathematics, U. S. Navy.

Rear-Admiral B. F. SANDS, U. S. N.,
Superintendent U. S. Naval Observatory, Washington, D. C.

[illegible]

[illegible]

[illegible]

Means [illegible]	[illegible]	Means	49 55 0.0 · 9 6 59.0
Index Corr., &c.	[illegible]	Index Corr., &c.	− 12.7
☉ [illegible]	[illegible]	☉	49 54 47.3
Refraction	[illegible]	Refraction	− 2 2.3
Parallax	[illegible]	Parallax	+ 3.2

Polar Distance of Object . . .	113 9 48.2	Polar Distance of Object . . .	113 9 50.0
	h. m. s.		h. m. s.
Local Apparent Time	10 4 22.5	Local Apparent Time	10 15 22.4
Equation of Time	5 39.8	Equation of Time	− 5 39.6
Local Mean Time	9 58 42.7	Local Mean Time	10 9 42.8
Time by Chronometer	8 55 59.8	Time by Chronometer	9 6 59.0
Chronometer slow of Local M.T. .	1 2 42.9	Chronometer slow of Local M.T. .	1 2 43.8
These observations were made before noon.		These observations were made before noon.	

ADDENDUM A—Continued.

SUN . . . DECEMBER 13.		
	On Arc = ω.	Off Arc = ω^1.
	′ ″	° ′ ″
	33 10	359 27 40
	10	40
	0	40
Index Corr.	− 0 23.4	
E	+ 8.5	
Index Corr., &c.	− 0 14.9	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	51 50 0	9 14 56.5
	52 0 0	15 56.5
	10 0	16 57.5
	51 20 0	18 31.0
	30 0	19 36.5
	40 0	20 36.5
Means	51 45 0.0	9 17 45.8
Index Corr., &c.	− 14.9	
Ω	51 44 45.1	Ther. 63.°
Refraction	− 1 57.4	in.
Parallax	+ 8.1	Bar. 30.27
		° ′ ″
Polar Distance of Object . . .		113 9 51.8
		h. m. s.
Local Apparent Time		10 26 8.9
Equation of Time		− 5 39.4
Local Mean Time		10 20 29.5
Time by Chronometer		9 17 45.8
Chronometer slow of Local M.T. .		1 2 43.7
These observations were made before noon.		

SUN . . . DECEMBER 13,		
	On Arc = ω.	Off Arc = ω^1.
	′ ″	° ′ ″
	32 50	359 27 40
	40	50
	35	50
Index Corr.	− 0 14.2	
E	+ 3.0	
Index Corr., &c.	− 0 11.2	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	22 45 0	2 25 9.5
	30 0	26 0.0
	15 0	26 49.5
	22 45 0	28 45.5
	30 0	29 35.5
	15 0	30 25.5
Means	22 30 0	2 27 47.6
Index Corr., &c.	− 11.2	
Ω	22 29 48.8	
Refraction	− 4 39.2	
Parallax	+ 8.8	
		° ′ ″
Polar Distance of Object . . .		113 10 43.3
		h. m. s.
Local Apparent Time		3 36 3.7
Equation of Time		− 5 33.2
Local Mean Time		3 30 30.5
Time by Chronometer		2 27 47.6
Chronometer slow of Local M.T. .		1 2 42.9
These observations were made after noon.		

NOTE.—The observations before noon on December 13 were made at the Prima Porta Terra, which is $0^s.13$ east of the Stone Gun-Platform.

ADDENDUM A—Continued.

SUN . . . DECEMBER 13.		
	On Arc = ω.	Off arc = ω¹.
	′ ″	° ′ ″
	32 45	359 27 50
	45	28 0
	50	28 0
Index Corr.	— 0 21.7	
E	+ 2.7	
Index Corr., &c.	— 0 19.0	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	20 45 0	2 31 49.0
	30 0	32 38.0
	15 0	33 27.5
	20 45 0	35 20.5
	30 0	36 10.5
	15 0	36 59.0
Means	20 30 0.0	2 34 24.1
Index Corr., &c.	— 19.0	°
Ω	20 29 41.0	Ther. 62.5
Refraction	— 5 5.5	in.
Parallax	+ 8.9	Bar. 30.22
		° ′ ″
Polar Distance of Object . . .		113 10 44.4
		h. m. s.
Local Apparent Time		3 42 40.3
Equation of Time		— 5 33.1
Local Mean Time		3 37 7.2
Time by Chronometer		2 34 24.1
Chronometer slow of Local M. T. .		1 2 43.1
These observations were made after noon.		

SUN . . . DECEMBER 14.		
	On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″
	33 10	359 27 50
	15	28 0
	20	27 50
Index Corr.	— 0 34.2	
E	+ 6.9	
Index Corr., &c.	— 0 27.3	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	44 0 0	8 35 41.0
	15 0	36 50.0
	30 0	37 59.5
	44 0 0	40 40.0
	15 0	41 50.0
	30 0	43 2.0
Means	44 15 0.0	8 39 20.4
Index Corr., &c.	— 27.3	
Ω	44 14 32.7	
Refraction	— 2 19.7	
Parallax	+ 8.3	
		° ′ ″
Polar Distance of Object . . .		113 13 34.1
		h. m. s.
Local Apparent Time		9 47 14.7
Equation of Time		— 5 11.5
Local Mean Time		9 42 3.2
Time by Chronometer		8 39 20.4
Chronometer slow of Local M. T. .		1 2 42.8
These observations were made before noon.		

ADDENDUM A—Continued.

SUN . . . DECEMBER 14.		
	On Arc $=\omega$.	Off Arc $=\omega^1$.
	′ ″	° ′ ″
	33 0	359 27 50
	0	50
	10	50
Index Corr.	− 0 26.6	
E	+ 7.5	
Index Corr., &c.	− 0 19.1	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	47 10 0	8 50 43.5
	20 0	51 32.0
	30 0	52 22.5
	46 40 0	53 38.5
	50 0	54 29.0
	47 0 0	55 19.5
Means	47 5 0.0	8 53 0.8
Index Corr., &c.	− 19.1	
Ω	47 4 40.9	
Refraction	− 2 10.5	
Parallax	+ 8.3	
		° ′ ″
Polar Distance of Object . . .		113 13 36.2
		h. m. s.
Local Apparent Time		10 0 55.9
Equation of Time		− 5 11.2
Local Mean Time		9 55 44.7
Time by Chronometer		8 53 0.8
Chronometer slow of Local M. T. .		1 2 43.9
These observations were made before noon.		

SUN . . . DECEMBER 14.		
	On Arc $=\omega$.	Off Arc $=\omega^1$.
	′ ″	° ′ ″
	33 15	359 27 40
	0	40
	15	50
Index Corr.	− 0 26.6	
E	+ 7.9	
Index Corr., &c.	− 0 18.7	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	49 0 0	9 0 7.5
	10 0	1 0.5
	20 0	1 55.5
	48 30 0	3 13.0
	40 0	4 10.0
	50 0	5 3.5
Means	48 55 0.0	9 2 35.0
Index Corr., &c.	− 18.7	°
Ω	48 54 41.3	Ther. 63.5
Refraction	− 2 5.1	in.
Parallax	+ 8.2	Bar. 30.28
		° ′ ″
Polar Distance of Object . . .		113 13 37.6
		h. m. s.
Local Apparent Time		10 10 30.6
Equation of Time		− 5 11.0
Local Mean Time		10 5 19.6
Time by Chronometer		9 2 35.0
Chronometer slow of Local M. T. .		1 2 44.6
These observations were made before noon.		

ADDENDUM A—Continued.

SUN . . . . DECEMBER 14.

	On Arc=ω.	Off Arc=ω¹.
	′ ″	° ′ ″
	32 40	359 28 10
	50	0
	45	0
Index Corr.	− 0 24.1	
E	+ 3.8	
Index Corr., &c.	− 0 20.3	
	2 Altitude.	**Chronometer.**
	° ′ ″	h. m. s.
	26 50 0	2 11 21.5
	40 0	11 56.5
	30 0	12 31.0
	27 10 0	13 57.0
	0 0	14 31.5
	26 50 0	15 5.5
Means	26 50 0.0	2 13 13.8
Index Corr., &c.	− 20.3	
Ω	26 49 39.7	
Refraction	− 3 55.5	
Parallax	+ 8.8	
		° ′ ″
Polar Distance of Object . . .		113 14 23.2
		h. m. s.
Local Apparent Time		3 21 2.8
Equation of Time.		− 5 4.8
Local Mean Time		3 15 58.0
Time by Chronometer		2 13 13.8
Chronometer slow of Local M. T. .		1 2 44.2

These observations were made after noon.

SUN . . . . DECEMBER 14.

	On Arc=ω.	Off Arc=ω¹.
	′ ″	° ′ ″
	32 40	359 28 0
	30	27 50
	40	27 55
Index Corr.	− 0 15.8	
E	+ 3.5	
Index Corr., &c.	− 0 12.3	
	2 Altitude.	**Chronometer.**
	° ′ ″	h. m. s.
	25 20 0	2 16 32.0
	10 0	17 7.0
	0 0	17 41.0
	25 50 0	18 31.0
	40 0	19 5.5
	30 0	19 39.5
Means	25 25 0.0	2 18 6.0
Index Corr., &c.	− 12.3	
Ω	25 24 47.7	
Refraction	− 4 8.7	
Parallax	+ 8.8	
		° ′ ″
Polar Distance of Object . . .		113 14 23.9
		h. m. s.
Local Apparent Time		3 25 55.0
Equation of Time.		− 5 4.7
Local Mean Time.		3 20 50.3
Time by Chronometer		2 18 6.0
Chronometer slow of Local M. T. .		1 2 44.3

These observations were made after noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 14.			SUN . . . DECEMBER 15.		
	On Arc $=\omega$.	Off Arc $=\omega^1$.		On Arc $=\omega$.	Off Arc $=\omega^1$.
	′ ″	° ′ ″		′ ″	° ′ ″
	32 40	339 28 0		33 0	359 28 15
	40	0		10	10
	50	0		20	10
Index Corr.	− 0 21.6		Index Corr.	− 0 40.8	
E	+ 3.2		E	+ 5.2	
Index Corr., &c.	− 0 18.4		Index Corr., &c.	− 0 35.6	
	2 Altitude.	Chronometer.		2 Altitude.	Chronometer.
	° ′ ″	h. m. s.		° ′ ″	h. m. s.
	23 30 0	2 22 49.0		35 10 0	8 0 1.0
	20 0	23 22.5		20 0	0 39.5
	10 0	23 55.5		30 0	1 17.5
	24 0 0	24 44.0		34 40 0	2 15.0
	23 50 0	25 18.0		50 0	2 53.0
	40 0	25 52.0		35 0 0	3 32.5
Means	23 35 0.0	2 24 20.2	Means	35 5 0.0	8 1 46.4
Index Corr., &c.	− 18.4	°	Index Corr., &c.	− 35.6	
Ω	23 34 41.6	Ther. 61.0	Ω	35 4 24.4	
Refraction	− 4 27.8	in.	Refraction	− 3 0.0	
Parallax	+ 8.8	Bar. 30.23	Parallax	+ 8.6	
		° ′ ″			° ′ ″
Polar Distance of Object . . .		113 14 24.7	Polar Distance of Object . . .		113 16 50.2
		h. m. s.			h. m. s.
Local Apparent Time		3 32 8.2	Local Apparent Time		9 9 13.6
Equation of Time		− 5 4.6	Equation of Time		− 4 43.4
Local Mean Time		3 27 3.6	Local Mean Time		9 4 30.2
Time by Chronometer		2 24 20.2	Time by Chronometer		8 1 46.4
Chronometer slow of Local M. T. .		1 2 43.4	Chronometer slow of Local M. T. .		1 2 43.8
These observations were made after noon.			These observations were made before noon.		

ADDENDUM A—Continued.

SUN . . . DECEMBER 15.

	On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″
	32 50	359 28 0
	33 0	0
	32 50	0
Index Corr.	− 0 26.6	
E	+ 5.5	
Index Corr., &c.	− 0 21.1	
	2 Altitude.	**Chronometer.**
	° ′ ″	h. m. s.
	37 0 0	8 7 5.5
	10 0	7 47.0
	20 0	8 26.0
	36 30 0	9 25.5
	40 0	10 5.0
	50 0	10 45.5
Means	36 55 0.0	8 8 55.8
Index Corr., &c.	− 21.1	
Ω	36 54 38.9	
Refraction	− 2 50.7	
Parallax	+ 8.6	

	° ′ ″
Polar Distance of Object . . .	113 16 51.1
	h. m. s.
Local Apparent Time	9 16 24.1
Equation of Time.	− 4 43.2
Local Mean Time.	9 11 40.9
Time by Chronometer	8 8 55.8
Chronometer slow of Local M. T. .	1 2 45.1

These observations were made before noon.

SUN . . . DECEMBER 15.

	On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″
	33 10	359 28 0
	0	0
	10	0
Index Corr.	− 0 33.4	
E	+ 5.8	
Index Corr., &c.	− 0 27.6	
	2 Altitude.	**Chronometer.**
	° ′ ″	h. m. s.
	38 30 0	8 13 6.0
	40 0	13 46.5
	50 0	14 27.5
	38 0 0	15 27.5
	10 0	16 9.5
	20 0	16 50.0
Means	38 25 0.0	8 14 57.8
Index Corr., &c.	− 27.6	°
Ω	38 24 32.4	Ther. 60.
Refraction	− 2 43.7	in.
Parallax	+ 8.5	Bar. 30.27

	° ′ ″
Polar Distance of Object . . .	113 16 52.0
	h. m. s.
Local Apparent Time	9 22 25.5
Equation of Time.	− 4 43.1
Local Mean Time.	9 17 42.4
Time by Chronometer	8 14 57.8
Chronometer slow of Local M. T. .	1 2 44.6

These observations were made before noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 15.		
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
	33 30	359 28 10
	30	10
	30	0
Index Corr.	− 0 48.4	
E	+ 5.4	
Index Corr., &c.	− 0 43.0	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	36 0 0	1 37 40.0
	35 50 0	38 20.5
	40 0	38 59.0
	36 30 0	39 57.0
	20 0	40 36.0
	10 0	41 15.5
Means	36 5 0.0	1 39 28.0
Index Corr., &c.	− 43.0	
Ω	36 4 17.0	
Refraction	− 2 53.6	
Parallax	+ 8.6	
		° ′ ″
Polar Distance of Object . . .		113 17 33.5
		h. m. s.
Local Apparent Time		2 46 49.3
Equation of Time		− 4 36.6
Local Mean Time		2 42 12.7
Time by Chronometer		1 39 28.0
Chronometer slow of Local M. T. .		1 2 44.7

These observations were made after noon.

SUN . . . DECEMBER 15.		
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
	33 20	359 28 10
	15	5
	15	0
Index Corr.	− 0 40.8	
E	+ 5.2	
Index Corr., &c.	− 0 35.6	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	34 50 0	1 42 14.0
	40 0	42 53.0
	30 0	43 32.0
	35 20 0	44 29.0
	10 0	45 6.0
	0 0	45 45.0
Means.	34 55 0.0	1 43 59.8
Index Corr., &c.	− 35.6	
Ω	34 54 24.4	
Refraction	− 2 59.6	
Parallax	+ 8.6	
		° ′ ″
Polar Distance of Object . . .		113 17 34.1
		h. m. s.
Local Apparent Time		2 51 20.1
Equation of Time		− 4 36.5
Local Mean Time		2 46 43.6
Time by Chronometer		1 43 59.8
Chronometer slow of Local M. T. .		1 2 43.8

These observations were made after noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 15.		
	On Arc = ω.	Off Arc = ω^1.
	′ ″	° ′ ″
	33 20	359 28 10
	15	0
	20	0
Index Corr.	— 0 40.8	
E	+ 4.9	
Index Corr., &c.	— 0 35.9	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	33 0 0	1 49 13.5
	32 50 0	49 51.0
	40 0	50 29.0
	33 30 0	51 24.0
	20 0	52 2.0
	10 0	52 38.5
Means	33 5 0.0	1 50 56.3
Index Corr, &c.	— 35.9	
Ω	33 4 24.1	Ther. 63.°
Refraction	— 3 9.9	in.
Parallax	+ 8.6	Bar. 30.25
		° ′ ″
Polar Distance of Object . . .		113 17 34.9
		h. m. s.
Local Apparent Time		2 58 16.8
Equation of Time		— 4 36.3
Local Mean Time		2 53 40.5
Time by Chronometer		1 50 56.3
Chronometer slow of Local M.T. .		1 2 44.2

These observations were made after noon.

SUN . . . DECEMBER 16.		
	On Arc = ω.	Off Arc = ω^1.
	′ ″	° ′ ″
	33 20	359 28 10
	20	10
	15	10
Index Corr.	— 0 44.2	
E	+ 4.1	
Index Corr., &c.	— 0 40.1	
	2 Altitude.	Chronometer.
	° ′ ″	h. m s.
	29 0 0	7 38 8.5
	10 0	38 43.5
	20 0	39 19.0
	28 30 0	40 12.0
	40 0	40 47.5
	50 0	41 23.0
Means	28 55 0.0	7 39 45.6
Index Corr., &c.	— 40.1	
Ω	28 54 19.9	
Refraction	— 3 38.8	
Parallax	+ 8.7	
		° ′ ″
Polar Distance of Object . . .		113 19 41.7
		h. m. s.
Local Apparent Time		8 46 44.1
Equation of Time		— 4 14.7
Local Mean Time		8 42 29.4
Time by Chronometer		7 39 45.6
Chronometer slow of Local M.T. .		1 2 43.8

These observations were made before noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 16.		
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
	33 0	359 27 40
	0	40
	10	40
Index Corr.	— 0 21.6	
E	+ 4.3	
Index Corr., &c.	— 0 17.3	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	30 10 0	7 42 17.5
	20 0	42 53.0
	30 0	43 29.5
	29 40 0	44 23.0
	50 0	44 59.0
	30 0 0	45 34.5
Means	30 5 0.0	7 43 56.1
Index Corr., &c.	— 17.3	
Ω	30 4 42.7	
Refraction	— 3 30.2	
Parallax	+ 8.7	
		° ′ ″
Polar Distance of Object		113 19 42.1
		h. m. s.
Local Apparent Time		8 50 56.0
Equation of Time		— 4 14.6
Local Mean Time		8 46 41.4
Time by Chronometer		7 43 56.1
Chronometer slow of Local M. T. .		1 2 45 3
These observations were made before noon.		

SUN . . . DECEMBER 16.		
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
	32 50	359 27 45
	55	28 0
	50	27 50
Index Corr.	— 0 21.7	
E	+ 4.6	
Index Corr., &c.	— 0 17.1	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	32 0 0	7 48 54.5
	10 0	49 33.0
	20 0	50 9.5
	31 30 0	51 5.5
	40 0	51 41.5
	50 0	52 18.5
Means	31 55 0.0	7 50 37.1
Index Corr., &c.	— 17.1	
Ω	31 54 42.9	Ther. 61°
Refraction	— 3 17.9	in.
Parallax	+ 8.7	Bar. 30.25
		° ′ ″
Polar Distance of Object . . .		113 19 42.9
		h. m. s.
Local Apparent Time		8 57 36.9
Equation of Time		— 4 14.5
Local Mean Time		8 53 22.4
Time by Chronometer		7 50 37.1
Chronometer slow of Local M. T. .		1 2 45.3
These observations were made before noon.		

ADDENDUM A—Continued.

SUN . . . DECEMBER 16.		
	On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″
	33 0	359 27 40
	32 55	40
	33 0	40
Index Corr.	− 0 19.2	
E	+ 4.6	
Index Corr, &c.	− 0 14.6	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	31 40 0	1 54 23.5
	30 0	55 0.0
	20 0	55 37.0
	32 10 0	56 31.0
	0 0	57 7.5
	31 50 0	57 46.5
Means	31 45 0.0	1 56 4.2
Index Corr., &c.	− 14.6	
Ω	31 44 45.4	
Refraction	− 3 16.3	
Parallax	+ 8.6	
		° ′ ″
Polar Distance of Object . . .		113 20 22.6
		h. m. s.
Local Apparent Time		3 2 55.4
Equation of Time.		− 4 7.0
Local Mean Time		2 58 48.4
Time by Chronometer		1 56 4.2
Chronometer slow of Local M. T. .		1 2 44.2

These observations were made after noon.

SUN . . . DECEMBER 16.		
	On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″
	32 55	359 27 50
	50	50
	55	45
Index Corr.	− 0 20.8	
E	+ 4.4	
Index Corr., &c.	− 0 16.4	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	30 30 0	1 58 40.0
	20 0	59 17.5
	10 0	59 54.0
	31 0 0	2 0 47.0
	30 50 0	1 23.5
	40 0	1 58.0
Means	30 35 0.0	2 0 20.0
Index Corr., &c.	− 16.4	
Ω	30 34 43.6	
Refraction	− 3 23.9	
Parallax	+ 8.7	
		° ′ ″
Polar Distance of Object . . .		113 20 23.0
		h. m. s.
Local Apparent Time		3 7 11.2
Equation of Time.		− 4 6.9
Local Mean Time		3 3 4.3
Time by Chronometer		2 0 20.0
Chronometer slow of Local M. T. .		1 2 44.3

These observations were made after noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 16.		
	On Arc = ω.	Off Arc = ω′.
	′ ″	° ′ ″
	32 50	359 27 40
	50	35
	40	40
Index Corr.	− 0 12.5	
E	+ 4.1	
Index Corr., &c.	− 0 8.4	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	28 30 0	2 5 52.0
	20 0	6 27.5
	10 0	7 2.5
	29 0 0	7 55.0
	28 50 0	8 31.0
	40 0	9 6.0
Means	28 35 0.0	2 7 29.0
Index Corr., &c.	− 8.4	
Ω	28 34 51.6	Ther. 67.
Refraction	− 3 38.3	in.
Parallax	+ 8.7	Bar. 30.18
		° ′ ″
Polar Distance of Object . . .		113 20 23.9
		h. m. s.
Local Apparent Time		3 14 21.0
Equation of Time		− 4 6.8
Local Mean Time		3 10 14.2
Time by Chronometer		2 7 29.0
Chronometer slow of Local M. T. .		1 2 45.2

These observations were made after noon.

SUN . . . DECEMBER 19.		
	On Arc = ω.	Off Arc = ω′.
	′ ″	° ′ ″
	32 40	359 27 35
	30	35
	50	25
Index Corr.	− 0 5.8	
E	+ 4.1	
Index Corr., &c.	− 0 1.7	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	29 10 0	7 40 44.5
	20 0	41 20.5
	30 0	41 56.0
	28 40 0	42 49.0
	50 0	43 25.5
	29 0 0	44 1.0
Means	29 5 0.0	7 42 22.8
Index Corr., &c.	− 1.7	
Ω	29 4 58.3	
Refraction	− 3 40.6	
Parallax	+ 8.7	
		° ′ ″
Polar Distance of Object . . .		113 25 36.8
		h. m. s.
Local Apparent Time		8 47 54.8
Equation of Time		− 2 45.9
Local Mean Time		8 45 8.9
Time by Chronometer		7 42 22.8
Chronometer slow of Local M. T. .		1 2 46.1

These observations were made before noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 19.

	On Arc = ω.	Off Arc = ω¹.
	° ′ ″	° ′ ″
	33 0	359 27 50
	0	45
	10	45
Index Corr.	− 0 25.0	
E	+ 4.3	
Index Corr., &c.	− 0 20.7	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	30 20 0	7 44 54.5
	30 0	45 29.5
	40 0	46 5.5
	30 0 0	47 38.0
	10 0	48 13.5
	20 0	48 49.5
Means	30 20 0.0	7 46 51.8
Index Corr., &c.	− 20.7	
Ω	30 19 39.3	
Refraction	− 3 31.4	
Parallax	+ 8.7	
		° ′ ″
Polar Distance of Object . . .		113 25 37.1
		h. m. s.
Local Apparent Time		8 52 23.4
Equation of Time.		− 2 45.8
Local Mean Time.		8 49 37.6
Time by Chronometer		7 46 51.8
Chronometer slow of Local M. T. .		1 2 45.8

These observations were made before noon.

SUN . . . DECEMBER 19.

	On Arc = ω.	Off Arc = ω¹.
	° ′ ″	° ′ ″
	33 0	359 27 45
	0	30
	0	40
Index Corr.	− 0 19.2	
E	+ 4.7	
Index Corr., &c.	− 0 14.5	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	32 30 0	7 52 49.5
	40 0	53 24.0
	50 0	54 5.0
	32 0 0	54 59.5
	10 0	55 37.0
	20 0	56 12.5
Means	32 25 0.0	7 54 31.2
Index Corr., &c.	− 0 14.5	
Ω	32 24 45.5	Ther. 53.°
Refraction	− 3 17.6	in.
Parallax	+ 8.6	Bar. 30.20
		° ′ ″
Polar Distance of Object . . .		113 25 37.4
		h. m. s.
Local Apparent Time		9 0 3.1
Equation of Time.		− 2 45.6
Local Mean Time.		8 57 17.5
Time by Chronometer		7 54 31.2
Chronometer slow of Local M. T. .		1 2 46.3

These observations were made before noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 19.			SUN . . . DECEMBER 19.		
	On Arc = ω.	Off Arc = ω¹.		On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″		′ ″	° ′ ″
	33 15	359 27 50		32 40	359 27 45
	0	28 0		33 0	45
	0	27 45		0	40
Index Corr.	— 0 28.4		Index Corr.	— 0 18.3	
E	+ 4.6		E	+ 4.4	
Index Corr., &c.	— 0 23.8		Index Corr., &c.	— 0 13.9	
	2 Altitude.	Chronometer.		2 Altitude.	Chronometer.
	° ′ ″	h. m. s.		° ′ ″	h. m. s.
	31 20 0	1 56 33.0		30 10 0	2 0 49.5
	10 0	57 14.5		0 0	1 27.0
	0 0	57 46.0		29 50 0	2 3.5
	31 50 0	58 41.0		30 40 0	2 56.0
	40 0	59 18.5		30 0	3 32.0
	30 0	59 54.5		20 0	4 9.0
Means	31 25 0.0	1 58 14.6	Means	30 15 0.0	2 2 29.5
Index Corr., &c.	— 23.8		Index Corr., &c.	— 13.9	
Ω	31 24 36.2		Ω	30 14 46.1	
Refraction	— 3 20.8		Refraction	— 3 28.6	
Parallax	+ 8.6		Parallax	+ 8.7	
		° ′ ″			° ′ ″
Polar Distance of Object . . .		113 25 55.7	Polar Distance of Object . . .		113 25 55.9
		h. m. s.			h. m. s.
Local Apparent Time		3 3 37.1	Local Apparent Time		3 7 52.0
Equation of Time		— 2 38.1	Equation of Time		— 2 38.0
Local Mean Time		3 0 59.0	Local Mean Time		3 5 14.0
Time by Chronometer		1 58 14.6	Time by Chronometer		2 2 29.5
Chronometer slow of Local M. T. .		1 2 44.4	Chronometer slow of Local M. T. .		1 2 44.5
These observations were made after noon.			These observations were made after noon.		

ADDENDUM A—Continued.

SUN . . . DECEMBER 19.		On Arc = ω.	Off Arc = ω'.
		° ′ ″	° ′ ″
		33 15	359 27 45
		10	50
		0	40
Index Corr.	−	0 26.6	
E	+	4.0	
Index Corr., &c.	−	0 22.6	
		2 Altitude.	**Chronometer.**
		° ′ ″	h. m. s.
		28 20 0	2 7 27.0
		10 0	8 2.0
		0 0	8 38.0
		28 50 0	9 30.0
		40 0	10 6.0
		30 0	10 41.5
Means		28 25 0.0	2 9 4.1
Index Corr., &c.	−	22.6	
Ω		28 24 37.4	Ther. 60.
Refraction	−	3 42.2	in.
Parallax	+	8.7	Bar. 30.12
			° ′ ″
Polar Distance of Object . . .			113 25 56.2
			h. m. s.
Local Apparent Time			3 14 26.7
Equation of Time			− 2 37.9
Local Mean Time			3 11 48.8
Time by Chronometer			2 9 4.1
Chronometer slow of Local M.T. .			1 2 44.7
These observations were made after noon.			

SUN . . . DECEMBER 21.		On Arc = ω.	Off Arc = ω'.
		° ′ ″	° ′ ″
		33 0	359 27 40
		0	30
		0	40
Index Corr.	−	0 18.4	
E	+	3.7	
Index Corr., &c.	−	0 14.7	
		2 Altitude.	**Chronometer.**
		° ′ ″	h. m. s.
		26 30 0	7 32 34.0
		40 0	33 7.5
		50 0	33 41.5
		26 0 0	34 34.5
		10 0	35 9.5
		20 0	35 43.5
Means		26 25 0.0	7 34 8.4
Index Corr., &c.	−	14.7	
Ω		26 24 45.3	
Refraction	−	3 55.1	
Parallax	+	8.8	
			° ′ ″
Polar Distance of Object . . .			113 27 12.4
			h. m. s.
Local Apparent Time			8 38 39.9
Equation of Time			− 1 46.1
Local Mean Time			8 36 53.8
Time by Chronometer			7 34 8.4
Chronometer slow of Local M.T. .			1 2 45.4
These observations were made before noon.			

ADDENDUM A—Continued.

SUN . . . . DECEMBER 21.		
	On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″
	32 30	359 27 30
	40	40
	40	30
Index Corr.	− 0 5.0	
E	+ 3.9	
Index Corr., &c.	− 0 1.1	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	27 40 0	7 36 37.0
	50 0	37 11.0
	28 0 0	37 46.5
	27 10 0	38 39.0
	20 0	39 13.5
	30 0	39 49.5
Means	27 35 0.0	7 38 12.7
Index Corr., &c.	− 1.1	
Ω	27 34 58.9	
Refraction	− 3 45.2	
Parallax	+ 8.7	
		° ′ ″
Polar Distance of Object . . .		113 27 12.4
		h. m. s.
Local Apparent Time		8 42 45.4
Equation of Time		− 1 46.0
Local Mean Time		8 40 59.4
Time by Chronometer		7 38 12.7
Chronometer slow of Local M. T. .		1 2 46.7

These observations were made before noon.

SUN . . . . DECEMBER 21.		
	On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″
	32 40	359 27 30
	50	25
	40	40
Index Corr.	− 0 7.5	
E	+ 4.2	
Index Corr., &c.	− 0 3.3	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	29 30 0	7 43 4.0
	40 0	43 39.5
	50 0	44 15.5
	29 0 0	45 11.0
	10 0	45 47.0
	20 0	46 22.0
Means	29 25 0.0	7 44 43.2
Index Corr., &c.	− 3.3	°
Ω	29 24 56.7	Ther. 64.
Refraction	− 3 31.0	in.
Parallax	+ 8.7	Bar. 29.86
		° ′ ″
Polar Distance of Object . . .		113 27 12.5
		h. m. s.
Local Apparent Time		8 49 16.1
Equation of Time		− 1 45.9
Local Mean Time		8 47 30.2
Time by Chronometer		7 44 43.2
Chronometer slow of Local M. T. .		1 2 47.0

These observations were made before noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 21.		
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
	33 0	359 27 40
	10	30
	0	40
Index Corr.	− 0 20.0	
E	+ 4.6	
Index Corr., &c.	− 0 15.4	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	31 20 0	1 57 24.5
	10 0	58 1.0
	0 0	58 38.0
	31 50 0	59 33.0
	40 0	2 0 9.0
	30 0	0 46.0
Means	31 25 0.0	1 59 5.2
Index Corr, &c.	− 15.4	
Ω	31 24 44.6	
Refraction	− 3 16.1	
Parallax	+ 8.6	
		° ′ ″
Polar Distance of Object . . .		113 27 16.6
		h. m. s.
Local Apparent Time		3 3 28.2
Equation of Time		− 1 38.1
Local Mean Time		3 1 50.1
Time by Chronometer		1 59 5.2
Chronometer slow of Local M. T. .		1 2 44.9

These observations were made after noon.

SUN . . . DECEMBER 21.		
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
Index Corr.	− 0 24.6	
E	+ 4.4	
Index Corr., &c.	− 0 20.2	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	30 11 0	2 1 38.5
	29 58 10	2 25.0
	50 20	2 53.0
	30 44 20	3 33.0
	36 10	4 3.0
	25 50	4 39.5
Means	30 17 38.3	2 3 12.0
Index Corr., &c.	− 20.2	
Ω	30 17 18.1	
Refraction	− 3 23.6	
Parallax	+ 8.7	
		° ′ ″
Polar Distance of Object . . .		113 27 16.6
		h. m. s.
Local Apparent Time		3 7 34.5
Equation of Time		− 1 38.0
Local Mean Time		3 5 56.5
Time by Chronometer		2 3 12.0
Chronometer slow of Local M. T. .		1 2 44.5

These observations were made after noon.

ADDENDUM A—Continued.

SUN . . . DECEMBER 21.			SUN . . . DECEMBER 22.		
	On Arc=ω.	Off Arc=ω'.		On Arc=ω.	Off Arc=ω'.
	′ ″	° ′ ″		′ ″	° ′ ″
	33 25	359 27 30		33 15	359 27 40
	25	40		0	35
	20	35		0	30
Index Corr.	− 0 29.2		Index Corr.	− 0 20.0	
E	+ 4.1		E	+ 3.7	
Index Corr., &c.	− 0 25.1		Index Corr., &c.	− 0 16.3	
	2 Altitude.	Chronometer.		2 Altitude.	Chronometer.
	° ′ ″	h. m. s.		° ′ ″	h. m. s.
	29 4 30	2 5 38.0		26 40 0	7 33 38.0
	28 52 40	6 24.5		50 0	34 12.5
	33 50	7 28.5		27 0 0	34 48.0
	29 26 20	8 13.5		26 10 0	35 39.5
	3 10	9 36.5		20 0	36 14.0
	28 54 20	10 6.5		30 0	36 49.5
Means	28 59 8.3	2 7 54.6	Means	26 35 0.0	7 35 13.6
Index Corr., &c.	− 25.1		Index Corr., &c.	− 16.3	
Ω	28 58 43.2	Ther. 64.6°	Ω	26 34 43.7	
Refraction	− 3 32.8	in.	Refraction	− 3 54.8	
Parallax	+ 8.7	Bar. 29.70	Parallax	+ 8.8	
		° ′ ″			° ′ ″
Polar Distance of Object . . .		113 27 16.7	Polar Distance of Object . . .		113 27 18.0
		h. m. s.			h. m. s.
Local Apparent Time		3 12 17.2	Local Apparent Time		8 39 15.2
Equation of Time		− 1 37.9	Equation of Time		− 1 16.0
Local Mean Time		3 10 39.3	Local Mean Time		8 37 59.2
Time by Chronometer		2 7 54.6	Time by Chronometer		7 35 13.6
Chronometer slow of Local M. T. .		1 2 44.7	Chronometer slow of Local M. T. .		1 2 45.6
These observations were made after noon.			These observations were made before noon.		

ADDENDUM A—Continued.

SUN . . . DECEMBER 22.			SUN . . . DECEMBER 22.		
	On Arc = ω.	Off Arc = ω'.		On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″		′ ″	° ′ ″
	32 50	359 27 45		32 50	359 27 40
	33 15	45		33 15	40
	10	28 0		10	40
Index Corr.	— 0 27.5		Index Corr.	— 0 22.5	
E	+ 3.9		E	+ 4.2	
Index Corr., &c.	— 0 23.6		Index Corr., &c.	— 0 18.3	
	2 Altitude.	Chronometer.		2 Altitude.	Chronometer.
	° ′ ″	h. m. s.		° ′ ″	h. m. s.
	27 50 0	7 37 41.5		29 40 0	7 44 13.0
	28 0 0	38 17.0		50 0	44 48.5
	10 0	38 51.0		30 0 0	45 23.5
	27 20 0	39 45.0		29 10 0	46 18.0
	30 0	40 20.0		20 0	46 54.0
	40 0	40 56.0		30 0	47 30.0
Means	27 45 0.0	7 39 18.4	Means	29 35 0.0	7 45 51.2
Index Corr., &c.	— 23.6		Index Corr., &c.	— 18.3	
Ω	27 44 36.4		Ω	29 34 41.7	Ther. 54.0°
Refraction	— 3 44.9		Refraction	— 3 30.9	
Parallax	+ 8.7		Parallax	+ 8.7	Bar. 29.42 in.
		° ′ ″			° ′ ″
Polar Distance of Object . . .		113 27 17.9	Polar Distance of Object . . .		113 27 17.9
		h. m. s.			h. m. s.
Local Apparent Time		8 43 19.6	Local Apparent Time		8 49 51.5
Equation of Time.		— 1 15.9	Equation of Time.		— 1 15.8
Local Mean Time		8 42 3.7	Local Mean Time		8 48 35.7
Time by Chronometer		7 39 18.4	Time by Chronometer		7 45 51.2
Chronometer slow of Local M. T. .		1 2 45.3	Chronometer slow of Local M. T. .		1 2 44.5
These observations were made before noon.			These observations were made before noon.		

ADDENDUM B.

Observations for Latitude, made on the Stone Gun-Platform at Syracuse, Sicily, by Professor William Harkness, U. S. N., with the Sextant Stackpole & Brother No. 937, *Mercurial Artificial Horizon Ha.* 1, *and Chronometer T. S. & J. D. Negus No.* 1115.

[NOTE.—The barometer employed was a pocket aneroid, 1.9 inches in diameter, marked L. Casella, London, No. 1128. It was compensated for temperature, and, in order to reduce its observed readings to the corresponding readings of a mercurial barometer at 32° F., it is only necessary to subtract from them 0.12 of an inch.]

SUN . .	DECEMBER 13, 1870.	
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
	32 40	359 28 0
	45	27 50
	33 5	28 0
	5	28 10
Index Corr.	− 0 26.9	
E	+ 10.0	
Index Corr., &c.	− 0 16.9	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	59 48 50	11 9 57.0
	45 50	11 20.5
	44 40	11 51.0
	58 38 30	12 34.0
	34 40	14 8.5
	33 35	14 33.5
Means	59 11 0.8	11 12 24.1
Index Corr., &c.	− 16.9	
Ω	59 10 43.9	Ther. 66.0°
ζ	60 24 38.0	Bar. 30.26 in.
Refraction	+ 1 39.7	
Parallax	− 7.8	
Am_0	− 11 57.1	
Bn_0	+ 0.7	
ζ_1	60 14 13.5	
δ	− 23 10 10.8	
φ	+ 37 4 3.	
		h. m. s.
Time of Culmination		11 54 22.9
Chronometer slow		1 2 43.2
Chron. Time of Culmination . .		10 51 39.7

POLARIS .	DECEMBER 14, 1870.	
	Coincidence of Images.	
	′ ″	
	0 55	
	45	
	50	
Index Corr.	− 0 50.0	
E	+ 14.0	
Index Corr., &c.	− 0 36.0	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	76 37 50	8 27 19.0
	34 30	29 27.0
	35 30	31 35.0
	35 30	33 13.5
	34 30	34 19.0
	34 0	35 11.5
Means	76 35 18.3	8 31 50.8
Index Corr., &c.	− 36.0	
Ω	76 34 42.3	Ther. 59.0°
½Ω	38 17 21.2	Bar. 30.26 in.
Refraction	− 1 12.8	
p cos t	− 1 12 13.2	
2d term	+ 11.0	
φ	+ 37 4 6.	
		h. m. s.
Chronometer slow		1 2 43.7
t		1 55 48.5
δ		88° 37′ 28″.0
p		4952″.0

ADDENDUM B—Continued.

POLARIS . . DECEMBER 14.

		Coincidence of Images.	
		′ ″	
		1 0	
		0 55	
		1 0	
Index Corr.	−	0 58.3	
E	+	14.0	
Index Corr., &c.	−	0 44.3	

		2 Altitude.	Chronometer.
		° ′ ″	h. m. s.
		76 32 50	8 36 1.5
		33 30	36 54.0
		33 30	37 39.0
		32 10	38 21.0
		31 40	39 26.5
		31 30	40 19.5
Means		76 32 31.7	8 38 6.9
Index Corr., &c.	−	44.3	
Ω		76 31 47.4	
½Ω		38 15 53.7	
Refraction	−	1 12.8	
$p \cos t$	−	1 11 5.7	
2d term	+	12.1	
φ	+	37 3 47.	

	h. m. s.
Chronometer slow	1 2 43.7
t	2 2 5.6
δ	88° 37′ 28″.0
p	4952″.0

SUN . . . DECEMBER 16.

		On Arc = ω.	Off Arc = ω¹.
		′ ″	° ′ ″
		33 0	359 27 50
		10	50
		0	50
Index Corr.	−	0 26.6	
E	+	10.0	
Index Corr., &c.	−	0 16.6	

		2 Altitude.	Chronometer.
		° ′ ″	h. m. s.
		59 47 40	10 54 47.5
		47 30	55 38.5
		47 40	56 1.5
		58 42 10	57 0.0
		41 30	57 38.5
		41 20	58 16.0
Means		59 14 38.3	10 56 33.7
Index Corr., &c.	−	16.6	
Ω		59 14 21.7	
ζ		60 22 49.2	
Refraction	+	1 39.8	
Parallax	−	7.8	
Δm	−	22.3	
ζ_1		60 23 59	
δ	−	23 20 3	
φ	+	37 3 56	

	h. m. s.
Time of Culmination	11 55 49.3
Chronometer slow	1 2 44.2
Chron. Time of Culmination . .	**10 53 5.1**

ADDENDUM B—Continued.

SUN . . . . DECEMBER 16.		
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
	33 0	359 28 10
	0	27 50
	20	45
Index Corr.	− 0 30.8	
E	+ 10.0	
Index Corr., &c.	− 0 20.8	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	58 41 0	10 58 50.0
	40 30	59 19.0
	40 15	59 52.5
	59 44 30	11 0 56.5
	43 50	1 39.5
	43 30	2 8.0
Means	59 12 15.8	11 0 27.6
Index Corr., &c.	− 20.8	
Ω	59 11 55.0	Ther. 64.5°
ζ	60 24 2.5	in.
Refraction	+ 1 39.8	Bar. 30.21
Parallax	− 7.8	
Am_0	− 1 32.4	
ζ_1	60 24 2.	
δ	− 23 20 4.	
φ	+ 37 3 58.	

		h. m. s.
Time of Culmination		11 55 49.3
Chronometer slow		1 2 44.2
Chron. Time of Culmination . .		10 53 5.0

POLARIS . . DECEMBER 16.		
	Coincidence of Images.	
	′ ″	
	0 20	
	30	
	25	
Index Corr.	− 0 25.0	
E	+ 14.1	
Index Corr., &c.	− 0 10.9	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	76 48 30	5 27 41.0
	50 30	29 42.0
	49 40	30 50.0
	48 45	31 55.0
	50 10	32 49.0
	50 10	33 33.5
Means	76 49 37.5	5 31 5.1
Index Corr., &c.	− 10.9	
Ω	76 49 26.6	
½Ω	38 24 43.3	
Refraction	− 1 12.6	
p cos t	− 1 19 56.5	
2d term	+ 2.9	
φ	+ 37 3 37.	

	h. m. s.
Chronometer slow	1 2 44.3
t	0 57 31.5
δ	88° 37′ 28″.4
p	4951″.6

ADDENDUM B—Continued.

POLARIS . . DECEMBER 16.		
	Coincidence of Images.	
	′ ″	
	0 30	
	30	
	35	
Index Corr.	− 0 31.7	
E	+ 14.2	
Index Corr., &c.	− 0 17.5	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	76 50 10	5 35 40.0
	51 0	36 39.0
	51 30	37 35.5
	51 0	38 54.0
	51 40	39 45.0
	51 40	40 53.5
Means	76 51 10.0	5 38 14.5
Index Corr., &c.	− 17.5	
Ω	76 50 52.5	Ther. 57.5°
½Ω	38 25 26.2	Bar. 30.20 in.
Refraction	− 1 12.6	
$p \cos t$	− 1 20 32.6	
2d term	+ 2.2	
φ	+ 37 3 43.	
Chronometer slow		h. m. s. 1 2 44.3
t		0 50 20.9

Star covered by haze, and very faint.

SUN . . . DECEMBER 17.		
	On Arc = ω.	Off Arc = ω¹.
	′ ″	° ′ ″
	33 15	359 28 0
	20	5
Index Corr.	− 0 40.0	
E	+ 10.0	
Index Corr., &c.	− 0 30.0	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	59 42 0	10 48 59.0
	42 30	50 0.0
	42 40	50 40.0
	58 38 5	51 50.0
	38 0	53 3.0
	38 0	53 47.0
Means	59 10 12.5	10 51 23.3
Index Corr., &c.	− 30.0	
Ω	59 9 42.5	
ζ	60 25 8.8	
Refraction	+ 1 39.6	
Parallax	− 7.8	
Δm,	− 12.5	
ζ_1	60 26 28.	
δ	− 23 22 25.	
φ	+ 37 4 3.	
Time of Culmination		h. m. s. 11 56 18.8
Chronometer slow		1 2 44.5
Chron. Time of Culmination . .		10 53 34.3

ADDENDUM B—Continued.

SUN . . . DECEMBER 17.		
	On Arc = ω.	Off arc = ω′.
	′ ″	° ′ ″
	33 0	359 27 40
	10	40
Index Corr.	− 0 22.5	
E	+ 10.0	
Index Corr., &c.	− 0 12.5	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	58 38 0	10 54 41.0
	38 5	55 18.0
	37 35	56 5.0
	59 42 45	57 3.0
	42 10	57 52.0
	41 30	58 45.0
Means	59 10 0.8	10 56 37.3
Index Corr., &c.	− 12.5	
Ω	59 9 48.3	Ther. 65°.
ζ	60 25 5.8	in.
Refraction	+ 1 39.6	Bar. 30.16
Parallax	− 7.8	
Am_0	− 18.7	
ζ_1	60 26 19.	
δ	− 23 22 26.	
φ	+ 37 3 53.	

	h. m. s.
Time of Culmination	11 56 18.8
Chronometer slow	1 2 44.5
Chron. Time of Culmination . .	10 53 34.3

SUN . . . DECEMBER 18.		
	On Arc = ω.	Off Arc = ω′.
	′ ″	° ′ ″
	33 0	359 27 45
	0	40
	10	35
Index Corr.	− 0 21.6	
E	+ 10.0	
Index Corr., &c.	− 0 11.6	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	59 39 10	10 53 32.0
	39 0	54 7.5
	39 10	54 33.5
	58 34 0	55 10.0
	33 35	55 40.5
	33 35	56 4.0
Means	59 6 25.0	10 54 51.2
Index Corr., &c.	− 11.6	
Ω	59 6 13.4	
ζ	60 26 53.3	
Refraction	+ 1 38.5	
Parallax	− 7.8	
Am_0	− 2.3	
ζ_1	60 28 22.	
δ	− 23 24 20.	
φ	+ 37 4 2.	

	h. m. s.
Time of Culmination	11 56 48.4
Chronometer slow	1 2 44.9
Chron. Time of Culmination . .	10 54 3.5

Observations taken through clouds.

ADDENDUM B—Continued.

SUN . . . DECEMBER 18.

	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	58 33 30	10 56 33.0
	33 25	57 6.0
	33 20	57 29.0
	59 38 0	58 7.0
	37 30	59 10.0
	36 50	11 0 6.5
Means	59 5 25.8	10 58 5.2
Index Corr., &c.	− 11.6	
Ω	59 5 14.2	Ther. 70.°
ζ	60 27 22.9	in.
Refraction	+ 1 38.5	Bar. 30.07
Parallax	− 7.8	
Am_0	− 29.2	
ζ_1	60 28 24.	
δ	− 23 24 21.	
ϕ	+ 37 4 3.	

	h. m. s.
Time of Culmination	11 56 48.4
Chronometer slow	1 2 44.9
Chron. Time of Culmination . .	10 54 3.5

Observations taken through clouds.

SUN . . . DECEMBER 19.

	On Arc $=\omega$.	Off Arc $=\omega^1$.
	′ ″	° ′ ″
	33 0	359 27 50
	10	45
	20	45
Index Corr.	− 0 28.4	
E	+ 10.0	
Index Corr., &c.	− 0 18.4	
	2 Altitude.	**Chronometer.**
	° ′ ″	h. m. s.
	59 33 20	10 46 44.0
	34 0	47 38.0
	34 50	48 34.0
	58 30 10	49 30.0
	30 20	50 13.0
	30 45	50 53.0
Means	59 2 14.2	10 48 55.3
Index Corr , &c.	− 18.4	
Ω	59 1 55.8	
ζ	60 29 2.1	
Refraction	+ 1 40.1	
Parallax	− 7.8	
Am_0	− 55.8	
ζ_1	60 29 39.	
δ	− 23 25 47.	
ϕ	+ 37 3 52.	

	h. m. s.
Time of Culmination	11 57 18.1
Chronometer slow	1 2 45.2
Chron. Time of Culmination . .	10 54 32.9

ADDENDUM B—Continued.

SUN . . .		DECEMBER 19.	
		On Arc = ω.	Off Arc = ω'.
		° ′ ″	° ′ ″
		33 15	359 27 30
		10	30
		15	30
Index Corr.	—	0 21.6	
E	+	10.0	
Index Corr., &c.	—	0 11.6	
		2 Altitude.	Chronometer.
		° ′ ″	h. m. s.
		58 30 50	10 51 35.0
		30 45	52 27.0
		31 10	53 7.0
		59 36 15	54 37.0
		36 15	56 16.0
		36 20	57 2.0
Means		59 3 35.8	10 54 10.7
Index Corr., &c.	—	0 11.6	
Ω		59 3 24.2	Ther. 64.
ζ		60 28 17.9	in.
Refraction	+	1 40.1	Bar. 30.16
Parallax	—	7.8	
Am_0	—	6.7	
ζ_1		60 29 44.	
δ	—	23 25 47.	
φ	+	37 3 57.	

	h. m. s.
Time of Culmination	11 57 18.1
Chronometer slow	1 2 45.2
Chron. Time of Culmination . .	10 54 32.9

POLARIS . .		DECEMBER 19.	
		Coincidence of Images.	
		° ′ ″	
		0 30	
		30	
		50	
Index Corr.	—	0 36.7	
E	+	14.2	
Index Corr., &c.	—	0 22.5	
		2 Altitude.	Chronometer.
		° ′ ″	h. m. s.
		76 54 30	6 29 37.5
		55 30	30 46.5
		55 30	31 48.0
		55 10	33 5.5
		55 10	35 23.5
		55 40	36 13.0
Means		76 55 15.0	6 32 49.0
Index Corr., &c.	—	22.5	
Ω		76 54 52.5	
½Ω		38 27 26.2	
Refraction	—	1 13.5	
$p \cos t$	—	1 22 18.7	
2d term	+	0.2	
φ	+	37 3 54.	

	h. m. s.
Chronometer slow	1 2 45.3
t	0 16 15.3
δ	88° 37′ 28″.9
p	4951″.1

ADDENDUM B—Continued.

POLARIS . . DECEMBER 19.		
	Coincidence of Images.	
	′ ″	
	0 20	
	40	
	20	
Index Corr.	− 0 26.7	
E	+ 14.2	
Index Corr., &c.	− 0 12.5	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	76 55 30	6 37 10.5
	56 10	39 4.0
	54 0	40 2.5
	55 0	41 16.5
	54 0	43 7.5
	55 10	45 45.5
Means	76 54 58.3	6 41 4.4
Index Corr., &c.	− 12.5	°
Ω	76 54 45.8	Ther. 49.5
½Ω	38 27 22.9	in.
Refraction	− 1 13.5	Bar. 30.13
p cos t	− 1 22 2.8	
2d term	+ 0.5	
ϕ	+ 37 4 7.	
		h. m. s.
Chronometer slow		1 2 45.3
t		0 24 32.0

SUN . . . DECEMBER 21.		
	On Arc = ω.	Off Arc = ω^1.
	′ ″	° ′ ″
	33 20	359 27 40
	15	30
	20	35
Index Corr.	− 0 26.6	
E	+ 10.0	
Index Corr., &c.	− 0 16.6	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	59 32 30	10 51 37.0
	32 30	52 2.0
	32 40	53 23.0
	58 27 35	59 8.5
	26 10	11 1 38.0
	25 55	1 58.5
Means	58 59 33.3	10 56 37.8
Index Corr., &c.	− 16.6	
Ω	58 59 16.7	
ζ	60 30 21.6	
Refraction	+ 1 38.3	
Parallax	− 7.8	
Δm,	− 34.1	
ζ_1	60 31 18.	
δ	− 23 27 15.	
ϕ	+ 37 4 3.	
		h. m. s.
Time of Culmination		11 58 18.1
Chronometer slow		1 2 45.9
Chron. Time of Culmination . .		10 55 32.2

ADDENDUM B—Continued.

SUN . . . . DECEMBER 21.		
	On Arc = ω.	Off Arc = ω'.
	′ ″	° ′ ″
	33 10	359 27 50
	15	40
	15	45
Index Corr.	− 0 29.2	
E	+ 10.0	
Index Corr., &c.	− 0 19.2	
	2 Altitude.	Chronometer.
	° ′ ″	h. m. s.
	58 25 10	11 2 38.5
	25 0	3 0.5
	24 50	3 25.5
	59 29 10	4 25.0
	28 30	5 0.0
	27 40	5 29.0
Means	58 56 43.3	11 3 59.8
Index Corr., &c.	− 19.2	
Ω	58 56 24.1	Ther. 67°.0
ζ	60 31 48.0	Bar. 29.77 in.
Refraction	+ 1 38.5	
Parallax	− 7.8	
Am_0	− 2 0.0	
ζ_1	60 31 19.	
δ	− 23 27 15.	
φ	+ 37 4 4.	

	h. m. s.
Time of Culmination	11 58 18.1
Chronometer slow	1 2 45.9
Chron. Time of Culmination . .	10 55 32.2

ADDENDUM C.

List of Articles forming part of the Equipment of the Expedition to Syracuse.

1 Achromatic Telescope of 3 inches aperture and 43½ inches focus, equatorially mounted, and provided with the necessary eye-pieces, shade-glasses, dew-cap, caps for reducing aperture of object-glass, counterpoises, adjusting tools, &c.
1 Single-Prism Spectroscope, with an adapter for attaching it to the telescope, shade-glasses for observing spectrum of the sun, and a lantern for illuminating the micrometer scale.
1 Arago Polariscope of double rotation, for use in the hand.
1 Arago Polariscope, and 1 Savart Polariscope, fitted for use with a telescope.
1 Six-inch Sextant, having a thermometer packed in the same case with it.
1 Mercurial Artificial Horizon.
1 Pocket Sextant.
1 Black-glass Artificial Horizon, provided with inclined planes for measuring zenith distances up to 130°.
1 Prismatic Compass.
1 Small Reflecting Level.
2 Pocket Compasses.
1 50-foot Tape-Measure.
1 Binocular Field-Glass.
1 Pocket Telescope, and screw-clip for same.
1 Set of Colored Glasses.
1 Pocket Aneroid Barometer.
2 Pocket Thermometers.
1 Rain-Gauge.
1 Set of Drawing Instruments.
4 Mean-time Box Chronometers.
1 Leather Case, with strap, to carry a box chronometer removed from its gimbals.
1 Box, with lock and leather strap, to carry 4 box chronometers removed from their gimbals.
Pig lead, to be used for counterpoising telescope.
Olive oil for lubricating axes of stand for same.
Soft rags and camel's hair dusting brush for cleaning lenses.
1 Lantern, and ball of wick for same.
Burning-fluid for same, composed of 1 volume of spirits of turpentine mixed with 4 volumes of alcohol.
Candles and candlesticks.
1 Camp-stool.
Twine—coarse, medium, and fine.
Rope.
Wrapping paper.
1 7-foot American boat ensign, and halyards for same.
Crelle's Rechentafeln.
Bremiker's 6-Figure Logarithms.
Bowditch's 5-Figure Logarithms.
4-Figure Logarithms.
Loomis's Practical Astronomy.
Chauvenet's Spherical and Practical Astronomy.
Chauvenet's Trigonometry.
American Nautical Almanac for 1870.
English Nautical Almanac Circular, No. 12, giving path of the total solar eclipse of December 21–22, 1870.
Celestial Atlas.
Scale of tints for comparison with color of prominences.
English Admiralty Charts:
- North Coast of Sicily.
- East Coast of Sicily.
- Southern Coast of Sicily.
- Sardinia to Malta, including Sicily.
- Malta and Gozo Islands.
- Valetta Harbors, and the Coast Westward to Madalena Point.
- Syracuse Harbor.
- City and Bay of Palermo.

Blank forms for time, latitude, and spectroscope observations.
Foolscap, letter, and note paper.
Drawing and tracing paper.
Buff-colored paper.
Blotting paper.
Envelopes, assorted sizes.
Ink.
Pens and penholders.
Black lead pencils.
Blue and red pencils.
India rubber.
Paper-cutter.
Sealing-wax and wafers.
1 Small drawing board, ruler, and square.
1 Claw-hammer.
1 Hatchet.
1 Brace and bits.
3 Screw-drivers, assorted sizes.
1 Set of awls, and other small tools, contained in a hollow handle.
1 Pair flat pliers.
1 Pair round pliers.
1 Pair cutting pliers.
Sail-needles.
Screws and nails, assorted sizes.
Wire of assorted sizes.
6 sheets of sand and emery paper, assorted.

ADDENDUM D.

Letter of Captain Tupman, R. M. A., giving an Account of Observations made by him on the Total Solar Eclipse of December 22, 1870, *while assisting Professor Harkness at Syracuse.*

H. M. S. PRINCE CONSORT,
Malta, December 27, 1870.

MY DEAR PROFESSOR HARKNESS: According to promise, I send you the few remarks I have to make concerning the eclipse, so that you may know exactly whereabouts I kept your spectroscope during the totality.

It is no use my saying anything about your "finder," through which I observed the corona. If I give any details worth publishing you can add a description of the instrument. It struck me when looking at the spots on the sun that it was particularly good.*

At the first contact the telescope was steady, and my time is good.

When we were examining the adjustment of the pointer of the finder with the slit of the spectroscope, I kept the former on the upper cusp of the sun's crescent. The telescope was vibrating too much in the wind to judge if the adjustment was *very* accurate, but I do not think there was an error of one minute.

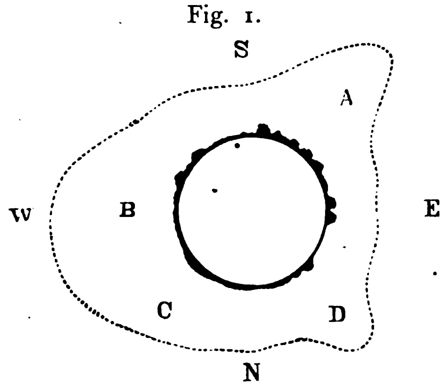
I am unaware of the position in which the slit was placed with respect to the vertical; but I remember that, facing the sun, the eye-telescope of the spectroscope was on the left and inclined very little upward, say fifteen degrees.

I watched the disappearance of the sun without the intervention of any coloring-glass whatever. The definition was perfect. The fine crescent shortened somewhat rapidly, then broke up at either end into several elongated beads of light, and finally disappeared with startling suddenness, when I gave you the time-signal. I could not hear the beats of the chronometer.

Up to this time I had not seen anything of the corona or protuberances, and I do not think the complete disk of the moon was visible; however, I did not take my eye off the disappearing limb of the sun. The ring of prominences and corona appeared as if by magic as the last ray of direct sunlight vanished. The brilliancy of the prominences quite startled me, especially of one a little to the right of the vertex. Their color, and that of the thin ring of light which united them, was a strong apricot pink, a color very difficult to match or describe. It was quite free from any tint of orange or vermilion, and unlike any color of the solar spectrum. The high protuberances appeared like electric lights attached to the limb of the moon. There was a break or interruption in the colored ring in the right lower quadrant, some twenty degrees long, between two not very conspicuous prominences, D., Fig. 1.

The body of the moon was considerably illuminated with a greenish-gray tint, similar to the *lumiere cendree* seen at new moon. I have no doubt the irregularities of the lunar surface might have been seen. The moon was not so dark as the sky beyond the corona, of which I had an extensive view from the size of the field.†

Fig. 1.



The first part of the corona that attracted my attention was a ray, or enlargement in the right upper quadrant, a little to the right of the very bright protuberance A, (Fig. 1;) but by the time you had done with the polariscope, which could hardly have been ten seconds, the left and lower left parts, B to C, were the largest and brightest, and so they remained until near the end of totality, when the part D, in the right lower quadrant, almost, if not quite, rivaled them. The ray D did not enlarge suddenly, but very gradually indeed. The upper part of the corona was throughout the faintest. The extreme right was also faint until quite at the end of totality, when it brightened a little No part increased in brilliancy without extending itself farther from the moon at the same time, so as to become a more or less pointed ray. I do not think any part of the corona extended farther than twenty-five minutes from the limb of the moon; no part was less than ten minutes, if so little.

* The finder attached to my telescope has an object-glass of 1.20 inches aperture, and 8.78 inches focal distance. The eye-piece used by Captain Tupman produced a power of 10 diameters. (W. H.)

† The field of view was 3° 15′ in diameter. (W. H.)

Of the *structure* of the corona I have the liveliest recollection. It was made up entirely of fine black lines, (that is, black enough to be distinctly visible,) on a white background, which commenced imperceptibly at a short distance from the chromosphere, and went off into the sky beyond. They were continuous and uniform, but unequally distinct and unequally distributed, although close together everywhere. There were no curved or crossed lines, or lines radiating from any other point.

The corona had no definite boundary. With the exception of the clearly-defined limit of the red flame-ring there was no other line of demarkation regularly or irregularly parallel to the moon's limb. It was white without a trace of any other color, and less intense than a bright white cloud, except at the base, which was very bright. The intensity diminished rapidly to a distance of five or six minutes, remained nearly uniform to near the outer limit, then faded off rather suddenly, although the unequal extension of the different parts gave it the appearance, as a whole, of fading off much more gradually. There was nothing *geometric* in its form, and the brighter portions, which were invariably those that extended the farthest, did not appear to have any relation of position with the prominences. The outer limits exhibited no coruscations, but faded off in the same uniform radial manner all round.

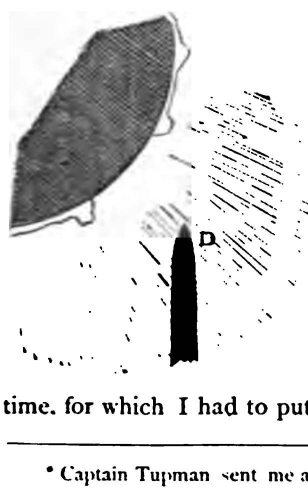
It is quite inconceivable that the corona could have presented the appearance it did to me if it be an atmosphere surrounding the sun to a distance of twenty-five or thirty minutes. My impression is that I was looking into a hollow cylinder of light, the inner surface of which was projected flatly on the plane perpendicular to the line of sight or axis. The change in the form and intensity of parts of the corona also seemed incompatible with its belonging to the sun.

I hardly feel justified in making a drawing, for, having concentrated my attention on keeping the pointer in the most favorable position for the spectroscope work, I did not make any estimations of angles of position, or of the extent or relative intensities of different parts. I chose the brightest parts, and remember whereabouts they were—but not exactly. Besides, my head was inclined considerably to my left, and my estimation of the position of the vertex may be considerably in error; but I am certain that the remarkably bright protuberance I noticed was very near the south point of the moon, then twenty-six and a half degrees to the right of the vertex.*

You will remember that during the partial phase we looked for a line of brighter light on the sun parallel to the limb of the moon. I once or twice fancied something of the kind, but the immediate contrast would account for it. I think it was with a power of eighty or ninety, with fair definition.† I also attentively observed the cusps and the limb of the moon. It would be difficult to imagine anything more striking than the extreme sharpness and *clearness* with which the light was cut off. The irregularities of the lunar surface were projected very sharply on the sun, affording ocular demonstration of the absence of any atmosphere on the moon.

I endeavored to keep the pointer at a distance of eight or ten minutes from the ring of prominences; but, the vibration of the telescope being about ten minutes on either side, the pointer oscillated between the limb of the moon and the outer part of the corona. I first placed it in the middle of the bright part B, (Fig. 1.) and gradually moved it down to C, and eventually on to D. Once I moved it from B right across to A; but as you then said you could see nothing I quickly went back to B. While examining the part D, the pointer remained very steady for several seconds opposite the middle of the interruption in the ring of prominences, the extreme point making about an equilateral triangle with the terminal protuberances, (Fig. 2.)

Fig. 2.



Of the ninety-five to one hundred seconds that you observed the spectrum the pointer was not ten near the ring of prominences. The spectrum of the chromosphere may have been very often visible when the silt was normal to the limb. From your exclamations at the time I know that the outer limit of the corona gave a *green* line, and it seems to me a most fortunate circumstance that the slit was open to the right extent.

The limb of the sun re-appeared very suddenly, and I at once noted the time, for which I had to put my face very close to the chronometer.

* Captain Tupman sent me a colored drawing which is reproduced in Plate I; except that the sky is there represented somewhat lighter, and the body of the moon somewhat darker, than in the original. (W. H.)

† The magnifying power was 65½ diameters. (W. H.)

The following are the times I noted by Negus 1115:*

	h.	m.	s.
First contact	11	35	30
Disappearance of the sun	1	0	9.5
Reappearance of the sun	1	1	55
Last contact	not observed.		

At Malta the first and last contacts were observed by M. Barthet, with an astronomical telescope of about two inches aperture, as follows:

	h.	m.	s.	
First contact	0	34	12	Valletta mean time.
Last contact	3	18	50	

The position of his observatory is 38 seconds of latitude north, and 0.6 second (of arc) of longitude west of "Spencer's Monument."† I had computed the time of first contact very accurately from the data in the British Nautical Almanac as $0^h\ 33^m\ 5^s$ for the Monument.

For Syracuse the predicted time of the first contact, computed from the British Nautical Almanac, was about ninety-five seconds too late; by the American Ephemeris only four seconds too late.

For the beginning of totality, the British time was about twenty-one seconds too early; the American about sixteen seconds too late.

The duration of the total phase was accurately predicted as one hundred and six seconds.

For the last contact Agnello's time, computed from British data, was $3^h\ 21^m\ 54^s$, and the observed times ranged from $3^h\ 21^m\ 39^s$ to $3^h\ 21^m\ 59^s$ Syracuse mean time.

I am, etc.,

G. L. TUPMAN,
Captain R. M. A.

---

* At the time of the eclipse Negus 1115 was $1^h\ 2^m\ 45^s.7$ slow of local mean-time. For a complete list of all the times of contact observed at Syracuse, see page 82. (W. H.)

† This, combined with the geographical determinations of the expedition, gives for the position of M. Barthet's observatory, atitude 35° 53′ 37″ north, longitude $0^h\ 58^m\ 4^s.5$ east of Greenwich. (W. H.)

REPORT

OF

PROFESSOR J. R. EASTMAN, U. S. N.

REPORT OF PROFESSOR J. R. EASTMAN, U. S. N.

UNITED STATES NAVAL OBSERVATORY,
Washington, D. C., March 1, 1871.

COMMODORE: I have the honor to present to you, in accordance with the orders of the Honorable Secretary of the Navy, the following report of my observations of the total solar eclipse at Syracuse, Sicily, on December 22, 1870.

In accordance with your instructions I provided myself with the following instruments: A telescope, equatorially mounted, by Clark, with an object-glass 3.25 inches in diameter; an aneroid barometer; dry and wet bulb thermometers; an actinometer, a photometer, and a Savart polariscope.

The above instruments are the same, except the photometer and polariscope, that I used in 1869, and are described in the Observatory Report of the Eclipse of August 7, 1869. The photometer is the same as described in that report, except that the tube has been shortened 3.5 inches, in order, if possible, to measure the relative amount of diffused light in the atmosphere during totality. The Savart polariscope was loaned me by Professor Harkness. It is constructed in the usual manner of a plate of quartz, cut obliquely to the axis, and a plate of tourmaline, but is mounted in a cell, and by means of an adapter was made to fit the telescope like an ordinary eye-piece. In London I completed my list of instruments by purchasing a solar and maximum and minimum thermometers, which had been tested at Kew.

All these instruments, but the telescope and polariscope, were a portion of my private collection.

In company with Professors Hall and Harkness, I left New York on the 2d of November, 1870, by the Cunard steamer China, for England, where I was detained two weeks before I could secure passage by steamer from Southampton to Malta. At Malta I was again delayed by the failure of the steamer, on account of a storm, in making her regular trip, but finally reached Syracuse on the 11th December.

The Prefect of Syracuse very kindly offered us our choice of observing stations, and we selected that bastion of the city wall, northwest of the Porta Terra, or gate toward the mainland. By the courtesy of the Prefect and of the Commandant of the Italian troops in Syracuse, we were allowed the use of an artillery store-house in this bastion for sheltering our instruments when not in use, and were not only constantly provided with a sentinel at the store-house gate during our stay in Syracuse, but Colonel Rossi furnished a strong guard on the day of the eclipse to prevent our being annoyed by crowds of idle wonderers from the city.

On unpacking the instruments the aneroid barometer was found to be somewhat damaged, probably owing to the severe usage which the box received when it was forced open by the customs officers in Liverpool.

The errors of the barometer were determined by comparison with another aneroid, and by frequent comparison I found that its relative indications were tolerably reliable, though utterly useless for absolute determinations except when almost constantly compared with another instrument.

After securing a double-roof protection for the meteorological instruments, I commenced on December 16 a series of observations to determine the normal meteorological conditions, as a standard with which to compare the changes that might occur during the eclipse.

I selected as my station for observing the eclipse the Stone Gun-Platform, 36⅔ yards south of the station chosen by Professor Harkness for observations for time. The meteorological instruments were stationed about four yards east of my observing station, the barometer being fifty-two feet above mean half-tide in the harbor of Syracuse.

It may be interesting, as showing something of the climate of Syracuse in December, to present the daily record of the observations, which I have accordingly done in the following tables. In these tables the

readings of the barometer have been corrected only for error in scale reading and for temperature, and the proper corrections have been applied to the readings of the thermometers.

Date.		Barometer.	Thermometers.			Wind.		Weather.	
			Dry.	Wet.	Solar.	Direction.	Force.	Clouds.	Portion cloudy.
1870.	h.	in.	°	°	°				
Dec. 16,	8	29.99	56.7	55.7	89.0	SE. . .	1	Cirrus . . .	1
	9	29.98	54.7	54.0	95.5	SE. . .	1	Cirrus . . .	1
	11	29.98	64.2	60.5	106.8	SE. . .	1	Clear . . .	0
	12	29.96	61.6	58.7	107.5	SE. . .	1	Clear . . .	0
	13	29.95	62.2	59.0	108.0	Calm .	0	Clear . . .	0
	14	29.94	64.4	59.0	108.5	Calm .	0	Clear . . .	0
	15	29.94	65.2	60.0	102.0	Calm .	0	Clear . . .	0
	16	29.94	62.7	57.0	100.5	Calm .	0	Clear . . .	0
	17	29.96	60.2	56.0	63.0	Calm .	0	Clear . . .	0
	18	29.96	57.2	55.0	55.0	Calm .	0	Stratus . . .	1
	19	30.00	57.2	53.0	55.0	Calm .	0	Stratus . . .	1
		Maximum, 66°.8.				Minimum, 46°.8.			
Dec. 17,	8	30.02	50.5	48.3	70.8	Calm .	0	Clear . . .	0
	9	30.02	54.7	53.0	87.0	Calm .	0	Clear . . .	0
	11	29.95	65.2	60.0	102.5	Calm .	0	Haze and cirri.	1
	12	29.93	67.3	60.0	103.5	Calm .	0	Haze and cirri.	1
	13	29.84	69.7	61.9	111.0	Calm .	0	Haze and cirri.	1
	14	29.84	68.5	61.3	110.2	Calm .	0	Haze and cirri.	1
	15	29.83	67.7	61.5	99.5	Calm .	0	Haze and cirri.	1
	16	29.82	68.2	61.3	96.0	Calm .	0	Haze and cirri.	1
	17	29.83	70.2	58.5	71.0	Calm .	0	Haze and cirri.	2
		Maximum, 73°.0.				Minimum, 49°.0.			
Dec. 18,	10	29.83	66.7	57.5	112.5	Calm .	0	Cirro-stratus .	2
	11	29.79	71.2	58.0	120.0	NW. .	2	Cirro-stratus .	3
	12	29.78	69.2	57.0	125.0	NW. .	2	Cirro-stratus .	4
	13	29.77	68.5	57.7	95.8	NW. .	1	Cirro-stratus .	5
	14	29.76	67.7	57.2	82.8	NW. .	1	Cirro-stratus .	8
	15	29.76	66.2	57.5	94.5	NW. .	1	Cirro-stratus .	8
	16	29.82	64.2	54.5	89.0	NW. .	1	Cirro-stratus .	7
	17	29.83	62.5	51.8	64.0	NW. .	1	Cirro-stratus .	5
		Maximum, 72°.9.				Minimum, 41°.0.			
Dec. 19,	8	29.97	44.7	41.5	76.5	Calm .	0	Clear . . .	0
	9	29.96	50.2	46.3	87.5	Calm .	0	Clear . . .	0
	10	29.94	55.7	49.0	102.0	Calm .	0	Clear . . .	0
	11	29.91	59.4	51.8	101.0	Calm .	0	Clear . . .	0
	12	29.89	60.7	52.9	107.5	S. . .	1	Clear . . .	0
	13	29.89	60.2	52.5	103.0	S. . .	1	Clear . . .	0
	14	29.89	61.2	53.0	102.0	S. . .	1	Clear . . .	0
	15	29.89	59.5	51.0	103.5	S. . .	1	Clear . . .	0
	16	29.88	58.2	50.8	104.0	Calm .	0	Clear . . .	0
	17	29.87	57.2	51.0	94.5	Calm .	0	Clear . . .	0
	18	29.89	52.2	47.5	55.5	Calm .	0	Clear . . .	0
	19	29.90	51.2	47.0	47.5	S. . .	1	Clear . . .	0
	20	29.92	48.7	46.0	48.0	Calm .	0	Clear . . .	0
		Maximum, 62°.2.				Minimum, 44°.0.			

Date.		Barometer.	Thermometers.			Wind.		Weather.	
			Dry.	Wet.	Solar.	Direction.	Force.	Clouds.	Portion cloudy.
1870.	h.	in.	°	°	°				
Dec. 20,	8	29.85	56.2	51.5	53.6	W. . .	1	Cumulo-stratus	9
	9	29.84	57.8	53.0	65.0	W. . .	2	Cumulo-stratus	9
	10	29.83	60.2	54.0	100.5	W. . .	2	Cumulo-stratus	6
	11	29.79	61.0	54.0	105.0	W. . .	2	Cumulo-stratus	3
	12	29.77	61.7	55.0	112.0	W. . .	4	Cumulo-stratus	2
	13	29.76	62.2	56.5	111.0	W. SW.	3	Clear . . .	0
	14	29.74	62.2	54.5	105.0	SW. . .	3	Clear . . .	0
	15	29.74	61.2	54.3	102.5	SW. .	3	Clear . . .	0
	16	29.75	59.2	53.0	95.5	SW. .	3	Clear . . .	0
	17	29.76	57.2	51.5	67.0	SW. .	3	Clear , . .	0
			Maximum, 63°.3.			Minimum, 49°.5.			
Dec. 21,	7	29.74	53.2	48.2	47.8	Calm . .	0	Cirro-stratus .	2
	8	29.74	56.2	50.2	85.5	Calm .	0	Cirro-stratus .	1
	9	29.71	57.2	52.2	89.5	Calm .	0	Cirro-stratus .	1
	10	29.68	62.2	55.2	105.0	SW. .	1	Cirrus . . .	1
	11	29.65	63.7	57.2	109.0	Calm .	0	Cirrus . . .	1
	12	29.62	64.2	58.0	113.9	SW. .	2	C. K. . . .	2
	13	29.60	65.7	59.0	113.0	SW. .	3	C. K. . . .	2
	14	29.57	65.7	58.5	110.5	SW. .	2	C. K. . . .	2
	15	29.59	63.8	59.6	108.0	SW. .	2	C. K. . . .	3
	16	29.61	61.7	58.0	83.0	SW. .	1	C. K. . . .	5
			Maximum, 66°.8.			Minimum, 47°.0.			

On the 21st there were unmistakable signs of the coming change in the weather. The barometer was unsteady, but gradually falling; the low bank of clouds, of a peculiar ashy hue, that hung over the Malta Channel, threatened wind from the S. W. or W., and during the entire day Etna was wrapped in a heavy mass of cumulus clouds. At 1^h a. m. on the 22d, a very light shower came on, with a slight sprinkle of snow, accompanied with lightning and thunder. At 7^h a. m. the clouds were quite dense near the horizon, but were clearing away near the zenith. The clouds seemed to condense near the horizon, and by 9^h 30^m a. m. only light flitting clouds were to be seen at the altitude of the sun. During the morning Etna was visible for about three hours, and it was evident that since the previous morning it had experienced a heavy fall of snow. The barometer was quite low during the morning, and in fact all day, and while Etna was visible in the morning there was an unusually large cloud of smoke or vapor flowing from the crater.

At 11^h a. m., I attempted to make a sketch of the spots on the sun, but the strong wind jarred my telescope so much that I was obliged to give up the idea.

In order to obtain the most and the best work in the shortest time, I arranged the following plan, which, so far as circumstances would permit, I was able to carry out in every respect:

1°. Observe first contact.

2°. Observe with the actinometer until five minutes before the beginning of totality, occasionally examining the edge of the advancing moon.

3°. Observe the time of the beginning of the total phase.

4°. With the polariscope observe—1°. The dark surface of the moon; 2°, the sky near the corona; 3°, the corona, especially the denser portions.

5°. Observe the time of the end of totality.

6°. Observe with the actinometer as before.

7°. Observe the time of last contact.

Mrs. Eastman was, as in 1869, to make the usual meteorological observations, and observe with the photometer at intervals of ten minutes during the progress of the eclipse, and during the total phase to make one observation, if possible, with the photometer, and read the solar thermometer once.

By noon the wind had considerably increased and the flying clouds were increasing in density.

At the time of first contact, though the sky was perfectly clear about the sun, the wind disturbed the telescope so much that I could not get a good image of the sun's limb at the point of contact, and the time of contact, as I observed it, $11^h\ 39^m\ 12^s$, by chronometer Negus 1340, which I used for all time observations on the 22d, must have been several seconds too late.

Soon after first contact I attempted to make some observations with the actinometer, but the increasing and quickly moving clouds prevented my getting more than two good readings, and though I made several subsequent trials at every favorable opportunity during the day, I did not succeed in getting a single complete set of observations.

After the first contact the cloudiness increased quite rapidly, and about twenty minutes before the totality a dense white cloud completely obscured the sun, its increasing proportions threatening to frustrate all our hopes for success. This cloud did not disappear by moving away in a mass, but seemed to melt away from a point in the vicinity of the sun, remains of it completely surrounding the sun until some minutes after totality. About four minutes before the total phase a rift, about three times the diameter of the sun, appeared in this cloud, through which the outline of the sun could be easily traced, and the light cirrus-like clouds that were constantly passing over this space were dense enough to enable me to examine the decreasing cusps of the sun without the aid of the colored shade for the eye-piece.

As the crescent of light gradually decreased the boundary of the aperture in the cloud grew somewhat larger and more distinct, with the sun apparently in the center of this cloud-frame, and the light, fleeting clouds that drifted across the face of the moon became less dense and moved with a lower velocity. After the obscuration of the sun by this cloud the wind increased considerably and blew in fitful gusts, while the chilly sensation, as of going into a deep cavern, came on suddenly and to such an extent that the addition of more clothing failed to counteract its effect. The phenomenon of total obscuration of the solar light was, of course, owing to the apparent difference of the relative diameters of the sun and moon, quite different from that in 1869.

In 1869 the thin crescent faded away very rapidly from the cusps toward the central line, while at the center there was an appreciable breadth of light; but at Syracuse the crescent of the same breadth was at least twice the angular length of that of 1869, and broke up into four pieces, all of them seeming to disappear at the same instant. Just previous to the totality I attached the polariscope by means of the adapter to the telescope and carefully adjusted the focus. The eye-piece connected with the polariscope had a magnifying power of 32, and with this eye-piece I observed the beginning and end of totality.

I noted the time of beginning of totality at $1^h\ 3^m\ 51^s.0$ by chronometer 1340. I immediately turned the telescope upon the dark face of the moon, and saw alternate dark and light bands of nearly equal intensity over the whole surface, but the distinction was a little less marked at the center of the moon. These bands were not changed in distinctness or tint during a complete revolution of the polariscope. I then moved the telescope so as to take successively into the field portions of a belt of the sky outside the visible limits of the corona, extending completely around the moon, but the alternate dark and light bands remained the same in tint, but varied in intensity or distinctness, according to the position of the clouds. Where the sky was nearly clear of clouds the definition of the bands was about the same as on the dark surface of the moon, but the definition was very much improved whenever a denser portion of the cloud was in the field. I then moved the telescope around the moon in such a way as to keep the lower and denser portion of the corona near the middle of the field, with results similar to those derived from the examination of the sky beyond the corona, except that the intensity of the tint of the bands was at its maximum when they were parallel or perpendicular to a tangent to the moon's limb. Once I thought I detected a faint tinge of green in the bands, but I was not able to see it again. I also saw a faint but decided red tinge in the bands over what I at first took to be a very dense portion of the corona, on the southwest limb of the sun, but on more careful scrutiny it proved to be a cloud moving easterly. I then turned the telescope for an instant to the bright edge of a cloud near the westerly limb of the sun, and there saw distinct traces of

color in the bands, though the tints were very faint. As it was now nearly time for the end of totality, I brought that portion of the moon's limb where the light of the sun would re-appear into the center of the field, and, during the few remaining seconds, carefully studied the appearance of the corona and the most conspicuous protuberance.

The structure of the corona appeared essentially the same as in 1869, and consisted of three distinct portions.

That portion next the edge of the moon, in many cases nearly obscured by the low and quite continuous range of protuberances which stretched along the limb of the sun for about 150°, was nearly white and resembled the denser portions of nebulæ. It seemed to be concentric with the sun, and I estimated its height, at the point near the large protuberance, at about one minute. The height of the next portion above the limb of the moon was about six minutes, and it had a decided radial structure, especially near the outer limit. Its color was silvery white. This portion seemed to be concentric with the sun, and its form was quite symmetrical, showing no change whatever in its outline in the vicinity of the protuberances.

The third and outer portion of the corona, on the western limb of the sun, consisted of three projections of light striated, or of a radial structure, resembling the short bands of streamers that are frequently seen rising from the auroral arch. One of these projections on the northwest limb of the sun was quite small, extending not more than five minutes above the limit of the second portion of the corona. The others, one on the southwest and one on the northwest limb of the sun, attained an altitude of about nine minutes above the second division of the corona.

The projections from the main portion of the corona were a silvery or grayish-white color, and the light was steady without any flickering.

Near the extremities of these projections they resembled very much the appearance of the sunlight as it passes through the interstices of the clouds near sunrise or sunset. The only protuberance which I noted carefully enough to enable me to sketch its position and outline, was located a little to the north of the point where the sun's light re-appeared. In form it resembled a mushroom, or the conventional representation of a waterspout, its outer limit being about two minutes above the limb of the moon. Its northern limit was quite smooth and regular, while the southern edge was rough and jagged, looking as if a strong current of wind was sweeping the lighter portions of its mass to the southward, and showing these rough edges and floating, irregular filaments in projection. The color of the southern end of this protuberance was a lighter pink than the main portion of the mass, or than the low range of protuberances, which I had no time to examine further than to note their color and general outline.

The end of totality was preceded by an increasing glow near the limb of the moon, south of the large protuberance, and announced by the bursting forth of a mass of light, shaped like the apex of a sugar-loaf, which spread north and south along the edge of the moon like a flash of lightning. This phenomenon I noted at $1^h\ 5^m\ 32^s.5$. At the end of totality I immediately finished my sketch of the corona and protuberances, and completed my fragmentary notes of the phenomena.

About fifteen seconds before the end of totality, the murmurs and exclamations of the people who had crowded into the open space between our guards and the prison, became so loud that I could not hear the beat of my chronometer, and Mrs. Eastman abandoned her general observations to count the second beats of the chronometer aloud.

During totality I felt some hard substance strike my face several times, and Mrs. Eastman noticed the fall of a few small hail-stones at that time. At about fifteen seconds before the end of totality the clouds and haze had nearly disappeared about the sun, and in five minutes afterward it was perfectly clear. Mrs. Eastman succeeded with all her contemplated observations except with the photometer, and only by her assistance was I enabled to observe the time of the end of totality.

Before totality the flying clouds so interfered with every set of observations with the photometer that their value was entirely destroyed, and during totality the whole aperture of the instrument did not admit light enough to illuminate the image at the base of the tube. After totality, the flying clouds, though they obscured the sun but a few minutes at a time, destroyed the value of the observations for the purposes of comparison, and they have therefore been entirely omitted.

The clouds gradually decreased, and about the time of last contact had entirely disappeared in the vicinity of the sun, while the wind had nearly died away. I observed the last contact with great care and very accurately, I think, at $2^h\ 22^m\ 53^s.5$.

The meteorological observations during the day, as made by Mrs. Eastman, are shown in the following table, where all the scale readings have been corrected when necessary, and the barometer readings have been corrected for temperature.

Date		Barometer.	Thermometers.			Wind.		Weather.	
			Dry.	Wet.	Solar.	Direction.	Force.	Clouds.	Portion cloudy.
1870.	h. m.	in.							
Dec. 22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W. by N.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W.	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Calm	[illegible]	C. K.	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W. by N.	[illegible]	[illegible]	[illegible]

Ma[ximum] temperature from December 21 [illegible] to December 22 [illegible] . . . . [illegible]

Mi[nimum] temperature from December 21 [illegible] to December 22 [illegible] . . . . [illegible]

Amount of rain and snow on the morning of the 22 [illegible] . . . . [illegible] mm.

Fig. [illegible] represents the [illegible] thermometers for six days and the observations of the [illegible].

Fig. [illegible] represents the [illegible] thermometer [illegible] and the observations of the [illegible].

On the morning of the [illegible] chronometer No. [illegible] was compared with No. [illegible] used by Prof[essor] Harkness, and I also compared them after the observation of the last contact. The following are the results:

No. [illegible]			No. [illegible]		
h.	m.	s.	h.	m.	s.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Fig. 1.

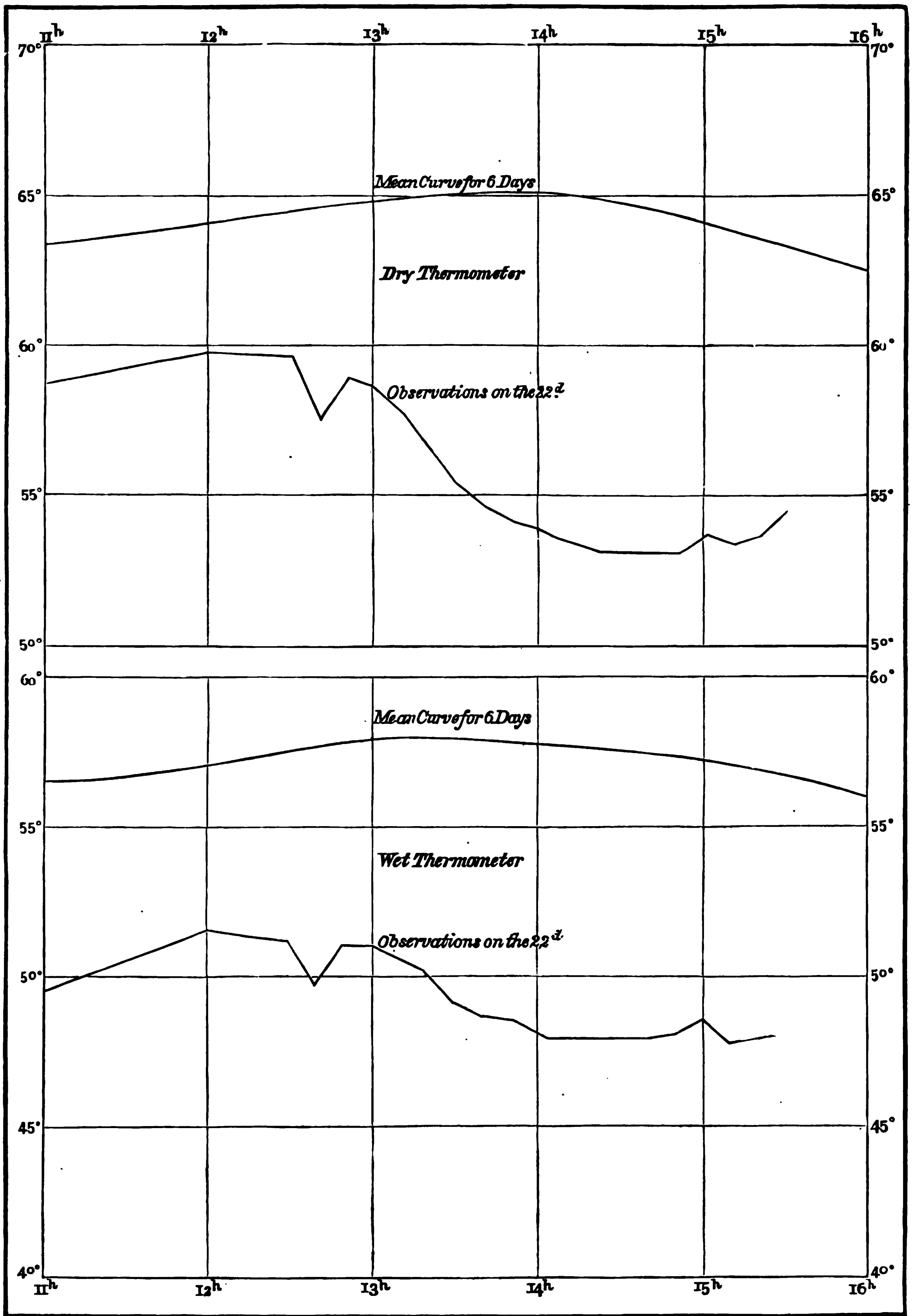


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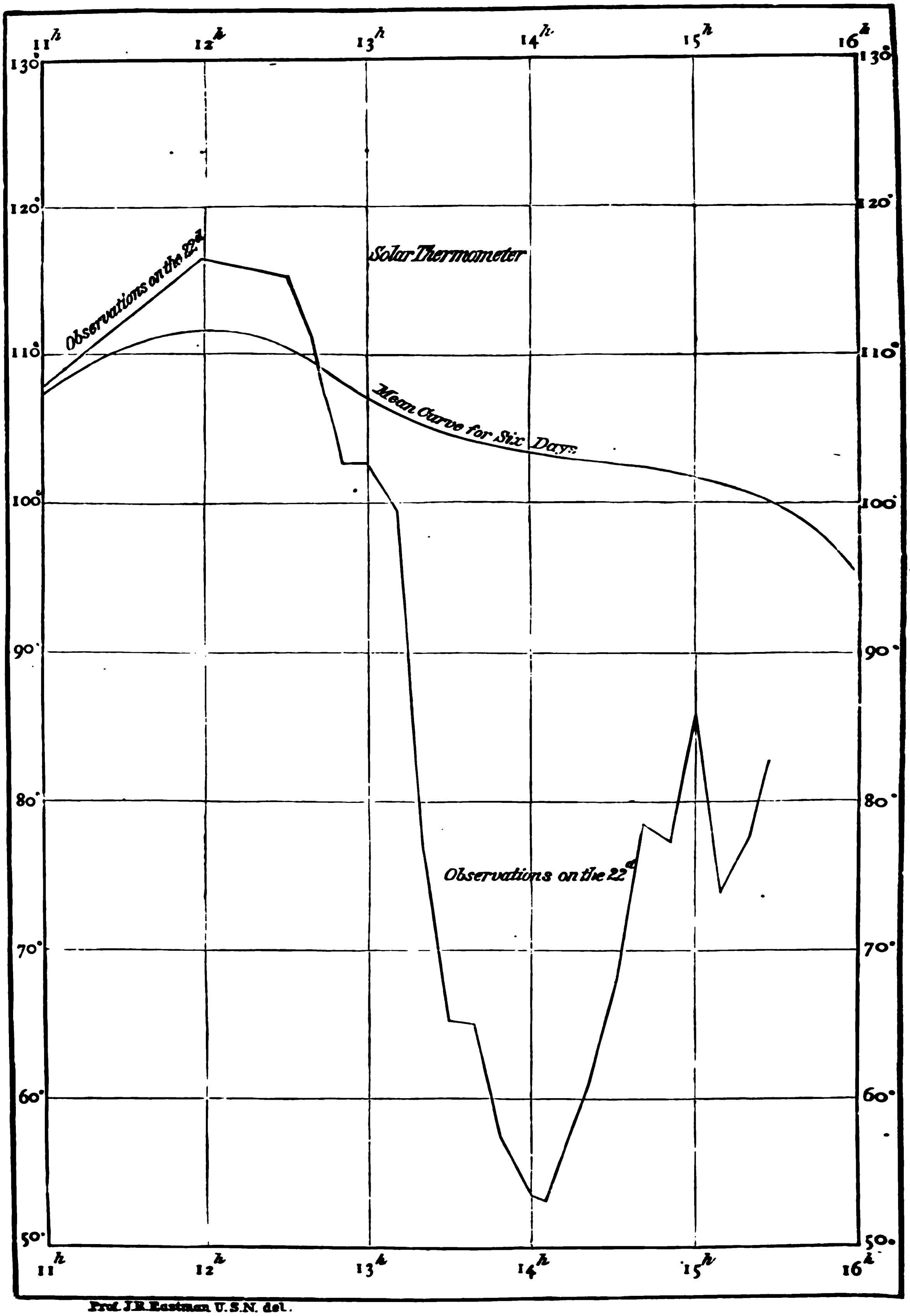
Fig. 2.



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From Professor Harkness's observations, No. 1115 was found to be $1^h\ 2^m\ 45^s.7$ slow of local mean time at both the morning and afternoon comparisons; hence the errors of No. 1340 when the comparisons were made were $-0^h\ 59^m\ 6^s.5$ and $-0^h\ 59^m\ 5^s.9$, with a gaining rate of $0^s.11$ an hour. Applying the corrections deduced from the above data to the observed times of contact, and comparing the results with the times computed by Professor Hall from the data in the American Nautical Almanac, assuming the latitude of Syracuse to be $+37°\ 3'\ 53''$ and the longitude $-6^h\ 9^m\ 25^s.6$ from Washington, we have the following table:

	Prof. Hall's Computed Time.			Observed Time.			C.—O.
	h.	m.	s.	h.	m.	s.	s.
First contact	0	38	15.8	0	38	18.2	− 2.4
Beginning of totality . .	2	3	1.8	2	2	57.1	+ 4.7
End of totality	2	4	43.0	2	4	38.6	+ 4.4
Last contact	3	22	5.1	3	21	59.4	+ 5.7

The accompanying sketch was made from the appearance of the phenomena in the telescope when the principal prominence was near the center of the field, just before the end of totality, and to avoid any chance for confusion the sketch has been finished in the inverted position in which it was seen in the telescope.

On the night of the 12th December I saw a few meteors, and the observations are given in Addendum A.

While in Malta I was greatly indebted to Mr. Lyell T. Adams, the American Consul, who spared no pains to make our forced stay an agreeable one; to Captain G. L. Tupman, of the English Navy, and Mr. Rosenbusch for many courtesies; and to Rear-Admiral Hastings R. Yelverton, commanding the English fleet in the Mediterranean, who very kindly offered to carry us to Syracuse in his dispatch-boat if the regular steamer did not go in season.

At Syracuse the American Consular Agent, Signor Nunzio Stella, was very assiduous in his courteous attentions to our party and rendered us all the aid we could desire, as did also Mr. Frederick Behn, the American Consul at Messina. I am also under obligations to the Prefect and the Syndic of Syracuse, to Colonel Rossi, Commandant of the King's troops in Syracuse, to Signor Bisani, the English Consul in the city, and to the Syndic of Augusta; in fact, this list might be extended to contain the names of all the government officials and scientific men whom I met in England or on the continent, since all manifested a strong desire to aid us officially and socially whenever an opportunity occurred.

As soon as the storm which came on after the eclipse had subsided, I left Sicily for the continent and reached Washington on the 18th February, 1871.

Very respectfully, your obedient servant,

J. R. EASTMAN,
Professor of Mathematics, U. S. Navy.

Commodore B. F. SANDS, U. S. N.,
Superintendent U. S. Naval Observatory, Washington, D. C.

ADDENDUM A.

Meteors observed at Syracuse, Sicily, December 12, 1870.

The observations were made from the tower of the "Albergo della Vittoria," and the tracks were recorded on a temporary chart hastily constructed for the occasion.

Only the southern portion of the heavens was mapped on this chart, as I intended to observe to the southward and note only such stars as might be seen by Captain G. L. Tupman at Valetta, Malta.

The time was taken from a pocket-watch, which, by comparison with our chronometers, was found to be fifty-five seconds slow of Syracuse mean time.

The times given in the following table have been reduced to Syracuse mean time.

Besides the meteors whose paths are given I saw thirteen that appeared in the east and the west, but beyond the limits of the chart.

Number.	Magnitude.	Time of Appearance.			Path.							
					Beginning.				End.			
		h.	m.	s.	h.	m.	°	′	h.	m.	°	′
1	3	8	42	25	3	10	− 17	0	2	36	− 23	30
2	4		45	10	2	32	+ 4	30	1	52	− 1	15
3	3	8	59	55	3	32	+ 22	30	3	1	+ 17	30
4	3	9	2	10	2	42	+ 21	30	2	9	+ 17	0
5	2		2	25	2	41	+ 20	0	1	47	+ 12	30
6	4		10	35	3	43	− 12	0	3	18	− 16	30
7	3		21	30	4	37	− 12	0	4	10	− 16	0
8	4		22	25	3	26	+ 7	30	3	22	+ 6	0
9	4		26	0	3	7	+ 1	30	2	28	− 6	0
10	3		35	45	4	0	− 5	30	3	32	− 10	0
11	3		42	40	4	2	+ 2	0	3	35	− 2	0
12	2		48	10	2	10	+ 10	30	1	33	+ 5	0
13	3	9	51	10	2	7	+ 13	30	1	36	+ 9	0

The light from all these meteors was white, but none of them left trains.

Most of them moved rapidly, but as I was observing alone I did not attempt to note the duration of each flight.

J. R. EASTMAN,
Professor of Mathematics, U. S. Navy.

The Total Solar Eclipse of December 22, 1870, as seen at Syracuse, with a 1⅕ inch telescope by Captain G. L. Tupman, R. M. A.

Plate I

The Total Solar Eclipse of December 22, 1870, as seen at Syracuse, with a $1\frac{1}{5}$ inch telescope by Captain G. L. Tupman, R. M. A.

Plate I

The Total Solar Eclipse of December 22, 1870, as seen at Syracuse, with a 1⅘ inch telescope by Captain G. L. Tupman, R. M. A.

Plate II.

Prof. J. R. Eastman, U.S.N. del.

Sketch of the Corona and Protuberances on the western limb of the Sun, near the end of the total phase of the eclipse of Dec. 22, 1870 by Prof. J. R. Eastman, U.S.N.